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INFLUENCE OF CLIMATOLOGICAL FACTORS IN THE DEVELOPMENT OF CERCOSPORELLA FOOT ROT OF WINTER WHEAT

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United States Department of Agriculture, Bureau of Plant Industry, in cooperation with the Oregon, Washington, and Idaho Agricultural Experiment Stations.

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INTRODUCTION

Cercosporella foot rot of winter wheat, caused by a soil-borne fungus, *Cercosporella herpotrichoides* Fron (*12*) [1], occurs in the United States in certain sod-grass prairies (*14*) in the Columbia River Basin of Oregon, Washington, and Idaho. It has been pointed out that, while the disease is not spreading very rapidly into other regions (*14*), it does, in its present range, fluctuate in severity from year to year (*15*). It is the purpose of this circular to present data on the influence of certain environmental conditions on the occurrence and severity of the disease as a means to determine proper agronomic practices for controlling the malady.

In the earlier years of this work the amount of disease present in a given field was expressed in percentage of diseased culms on a unit area. In most of the cases reported herein, however, the amount of injury, which is termed the "percentage injury", is based on a separation of the culms from a unit area into six classes according to the severity of the disease, as follows. (1) Healthy, (2) slight, (3) moderate, (4) severe, (5) very severe, and (6) dead. These classes were

[1] Italic numbers in parentheses refer to Literature Cited, p. 39.

described and their relative severity given in a previous article (*15*). In each case it will be made clear whether the estimate of the amount of injury is based on the percentage of diseased culms alone or on "percentage injury" basis.

EXPERIMENTAL STUDIES

The experimental studies were conducted in the field under natural conditions of infestation or in the greenhouse at Corvallis, Oreg., and the Arlington Experiment Farm, Arlington, Va., under controlled or partially controlled conditions.

SOIL-MOISTURE STUDIES

Studies on the possible relation of soil moisture to the development of cercosporella foot rot were conducted along the following lines: (1) Determination of wilting point coefficients of foot rot infested soils and (2) studies of soil moisture in relation to severity of foot rot. The latter studies were conducted both in the field and in the greenhouse.

DETERMINATION OF WILTING POINTS

By means of the Briggs and Shantz (*1*) method, the wilting-point coefficients were determined for the soils of a number of fields where foot rot occurred.

Buckwheat (*Fagopyrum esculentum* Moench) was used as a test plant in all light soils and the annual sunflower (*Helianthus annuus* L.) was used in the few heavy soils. The plants were grown during the winter months, in the greenhouse at Corvallis, in tin cans having a capacity of 12 liquid ounces and of the type usually termed tall "olive cans." When the plants were well rooted the soil was covered with paraffin. As a rule, it required from September to March for the plants to become permanently wilted. This so-called wilting was more of a xerosis than a drooping. The determinations were replicated five times on the soil samples taken at each location (station) and the wilting-point coefficients were averaged. The results are given in table 1.

TABLE 1.—*Wilting-point coefficients of foot rot infested soils in the Columbia River Basin*

General location	Stations	Soil type	Wilting-point coefficient
Oregon:	*Number*		
Elgin, Union County	1	Palouse series; very fine sandy loam.	12.2
Seven Mile Hill, Wasco County	4	Loam	5–7
Tygh Ridge, Wasco County	17	Fine sandy loam	7–8
Washington:			
Anatone, Asotin County	1	Palouse series (?) loam	14
High Prairie, Klickitat County	10	Fine sandy loam	6.8–8
Liberty Lake Junction, Spokane County	1	Garrison gravelly loam	3.4

Most of the soils except the darker types from near Elgin, Oreg., and Anatone, Wash., were characterized by low wilting-point coefficients. The extremely low wilting point for the station near Liberty Lake Junction, Wash., is explained by the fact that the soil contained considerable small gravel, the actual wilting point of the rock-free soil undoubtedly being somewhat higher.

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In the late winter, soon after the snow has disappeared, the total moisture in the surface soils of Tygh Ridge, Seven Mile Hill, and High Prairie approximates 30 percent, but as a rule it steadily decreases until by harvest it has reached a point considerably below the wilting coefficient. At times, late in the growing season, it was found that the top 3 inches of soil, where *Cercosporella herpotrichoides* is most abundant, contained only 2.5 percent of total soil moisture.

INFLUENCE OF AVAILABLE SOIL MOISTURE ON THE SEVERITY OF FOOT ROT

Studies to determine the possible relation of soil moisture to the development of foot rot were conducted (1) in infested fields in the Grande Ronde Valley of Oregon, near Imbler and Elgin, and in the Columbia Gorge area on Tygh Ridge, Oreg., and on High Prairie, Wash., and (2) in the greenhouse at Corvallis, Oreg.

FIELD STUDIES

Soil samples were collected and observations were made on the development of foot rot at each of several numbered locations in the different field studies. Each time the soil samples were taken, observations also were made on the development of foot rot at each location. In the earlier studies the soil samples were taken from the top 3-inch layer and also from the 6- to 9-inch level. After the first year it was found that the top 3 inches of soil was the layer chiefly concerned with the immediate development of the fungus; after that time, therefore, only the top 3-inch layer was studied, except at seeding time, when soil samples from the 6- to 9-inch layer also were taken. The percentage of total soil moisture and of available soil moisture in the various soil samples was determined in the usual way. Percentage losses from the foot rot organism were recorded according to the method previously described (*15*). The results obtained at the different localities will be discussed separately.

The field studies in the Grande Ronde Valley near Imbler, Oreg., were conducted on the C. Woodell ranch. The soil is a fine sandy loam. As shown in figure 1, *A*, the severity of the disease is greatest at the lower elevations in the field where the average soil-moisture percentages for April to July are highest.

Near Elgin, Oreg., the field studies were conducted on the H. Parson ranch (fig. 1, *B*). Here the soil is a very fine sandy loam, probably of the Palouse series. The soil-moisture stations extended along a level stretch of fertile ground where soil moisture and foot rot were both rather uniformly distributed. The slight variations in both were directly correlated.

The field studies in the Columbia Gorge area on Tygh Ridge, Oreg., were conducted on the Hunter ranch (fig. 1, *C*). Here also the soil was fine sandy loam. A contour map (fig. 2) in which the location of the numbered soil-moisture stations is indicated, shows that the area was rather large and included various exposures and elevations. There were also slight to moderate variations in soil types. The seasonal progress of the disease at the different stations in 1931 is shown in figure 3. The average available soil moisture for April 19, May 28, and July 2, 1931, is given in figure 1, *C*. The correlation in this series was obscured by a number of factors. As shown in figure 2, stations 19 to 21 were on the higher portions of the field and no

foot rot was present there nor has it occurred there in any year from 1929 to 1935. Station 18 was on a steep slope above a depression at station 17. Foot rot was present in station 17 but absent at station 18, the latter being so situated that heavy blankets of snow accumulate

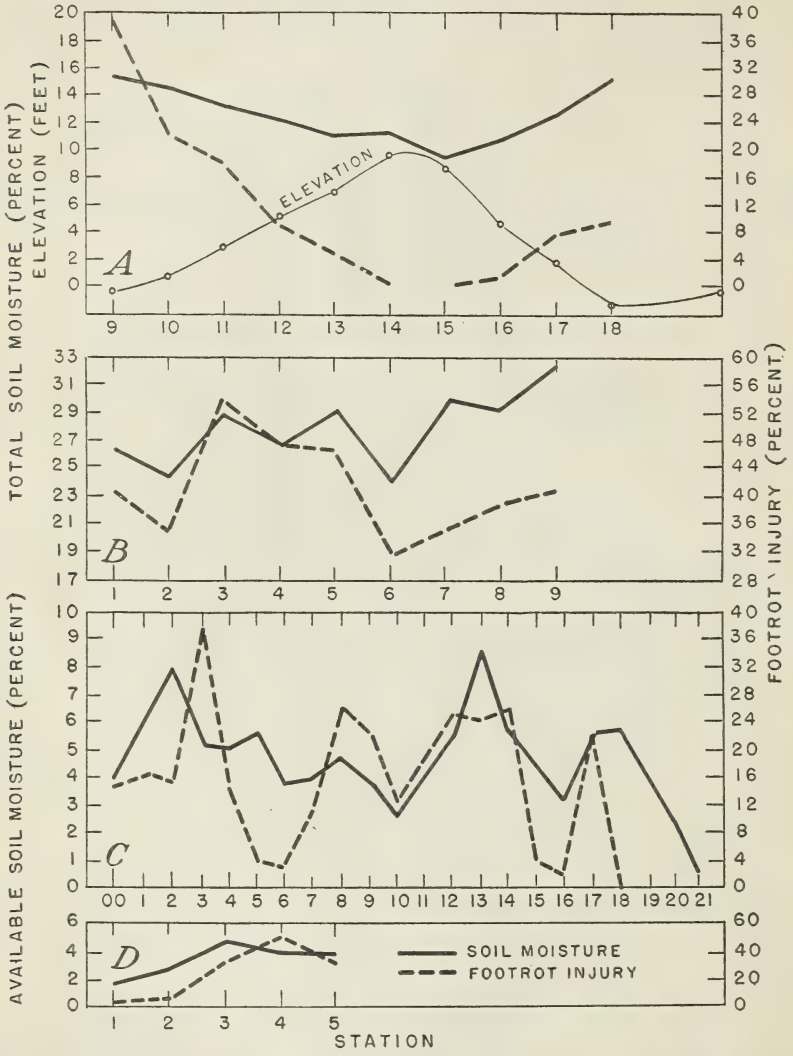


FIGURE 1.—Percentage injury from cercosporella foot rot and percentage soil moisture at numbered stations in infested wheat fields: *A*, Near Imbler, Oreg.; *B*, near Elgin, Oreg.; *C*, on Tygh Ridge, Wasco County, Oreg.; and *D*, on High Prairie, Klickitat County, Wash.

there and the wheat was retarded in growth. All observations show that wheat subjected to prolonged snow covering obtains such a late start that *Cercosporella herpotrichoides* does not have time to cause severe injury before the beginning of the hot dry season. Stations 5 and 6 were in soil filled with straw, where an old straw stack had been, and because of the abnormal condition should be disregarded in

relation to the present study. There was very little correlation in stations 4 to 1, which lay above a seepage area at station 0. The wheat in this depression made rank growth, which exhausted the soil moisture very early. During the season, with its exceedingly varying droughts and torrential rains, there was no observable correlation between foot rot and soil moisture.

It is evident from these data from Tygh Ridge that it is essential to avoid as many modifying factors as possible in studying soil moisture and foot rot development, particularly in a semiarid region.

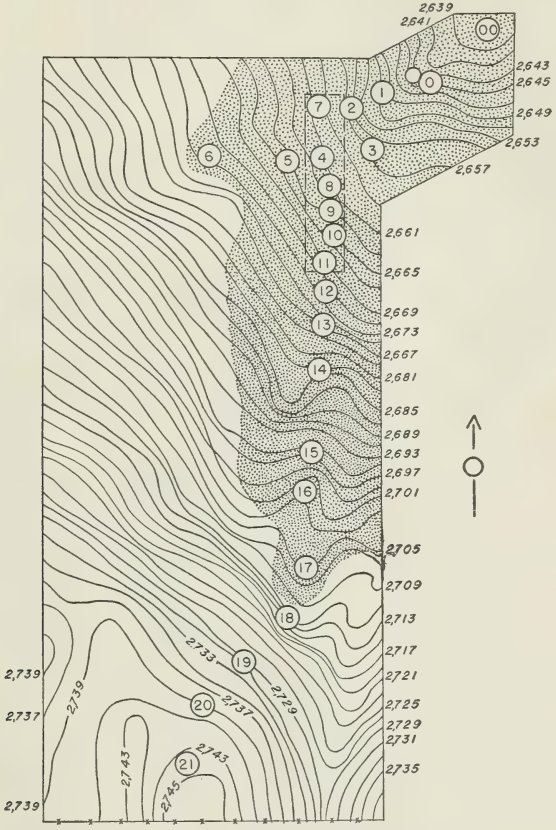


FIGURE 2.—Contour map of a field on Tygh Ridge, near Dufur, Oreg., with infested portion stippled, showing the location of the soil-moisture stations indicated by numbers in circles. The average percentage available soil moisture at the various stations is shown in figure 1, *C*. The location of the 1930–31 varietal test plot is shown by outline, extending from stations 7 to 11. An intermittent spring occurs at station 0.

On High Prairie, the field studies on soil moisture in relation to foot rot development were conducted on the C. A. Johnson ranch in the years 1930–31 and 1931–32 (fig. 1, *D*). The progress of the disease at 10 different soil-moisture stations from March to the early part of July 1931, and the distribution of rainfall at Goldendale, Wash., are given in figure 4. It is noted that stations 1, 2, 7, 8, 9, and 10, which were on the "white" soil phase (subsoil), had considerably less foot rot than stations 3, 4, 5, 6, and 11, which were on the more fertile, darker, very fine sandy loam soil. As shown in figure 1, *D*, for stations

1 to 5, there was again direct correlation between the average amount of available soil moisture and the resulting percentage of foot rot.

Observations in the same area, but in a different portion of the field, were continued in 1932 and the results are shown graphically in figure

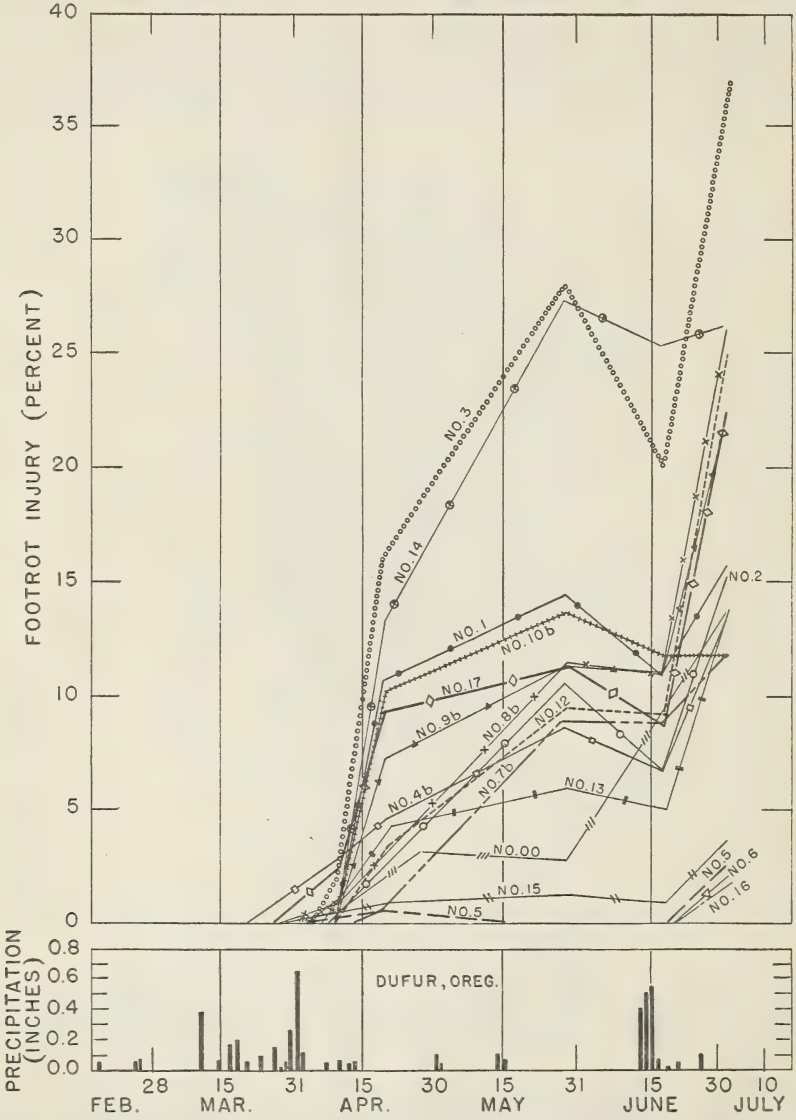


FIGURE 3.—Seasonal progress of cercosporella foot rot at different numbered soil-moisture stations in an infested field on Tygh Ridge, and precipitation at Dufur, Oreg., in 1931. The location and elevation (in feet) of the stations are shown in figure 2. Note the actual decrease in foot rot during the prolonged dry period in April and early May and the abrupt increase after the heavy rains in June.

5. Again they show a correlation between the average amount of available soil moisture and percentage injury from foot rot. However, the difference in the average amount of soil moisture available in stations 6 to 10, which belonged to the "white" phase soil, and the

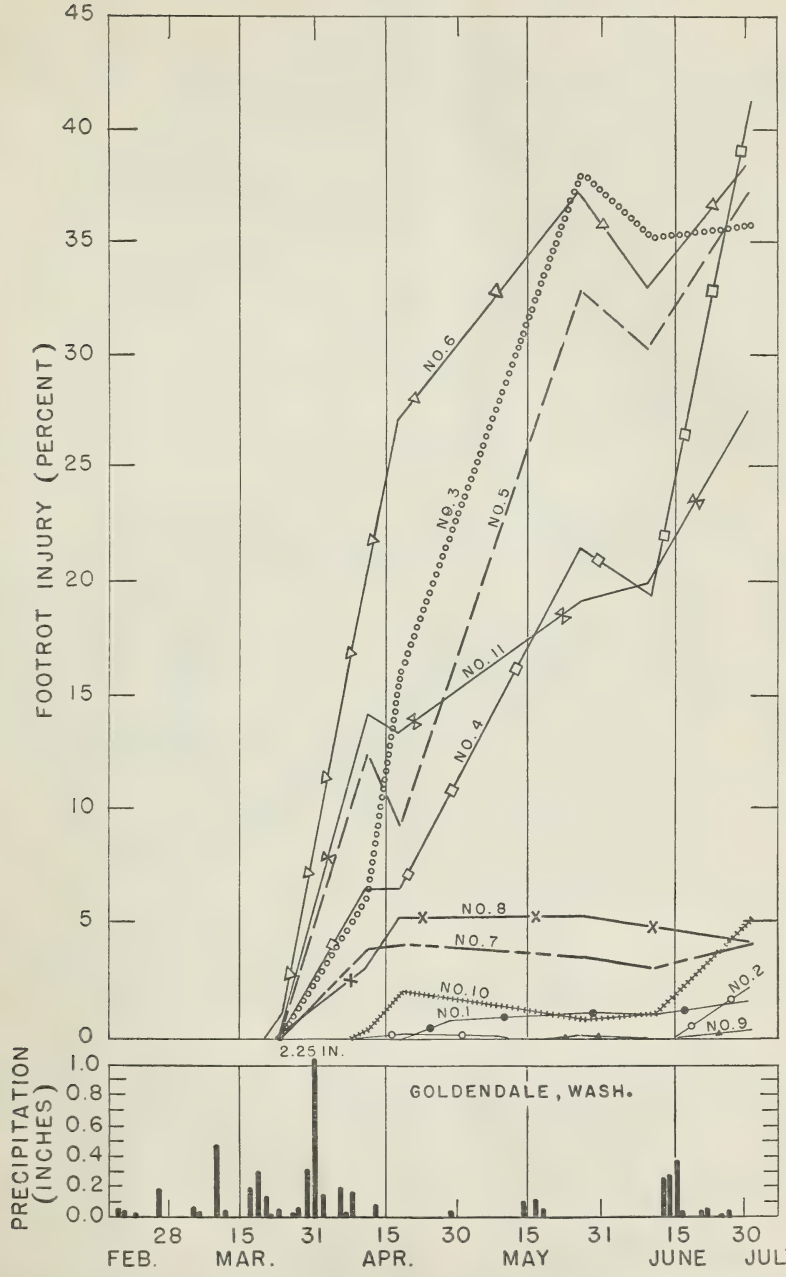


FIGURE 4.—Seasonal progress of cercosporella foot rot at different numbered soil-moisture stations in an infested field on High Prairie, Klickitat County, Wash., and the distribution of rainfall at Goldendale, Wash., February to July 1931. Note the slight decrease in foot rot during the prolonged dry period in April and early May and the abrupt increase after the heavy rains in June.

more fertile, darker phase (station 5, intermediate) was not nearly so great as the differences in percentages of foot rot present in these stations. In this case, the amount of soil moisture available at seeding time apparently was of far greater significance. The whiter phase puddles readily during rainy weather and dries quickly. The summer fallow in these places is always much drier than in the mellow, darker

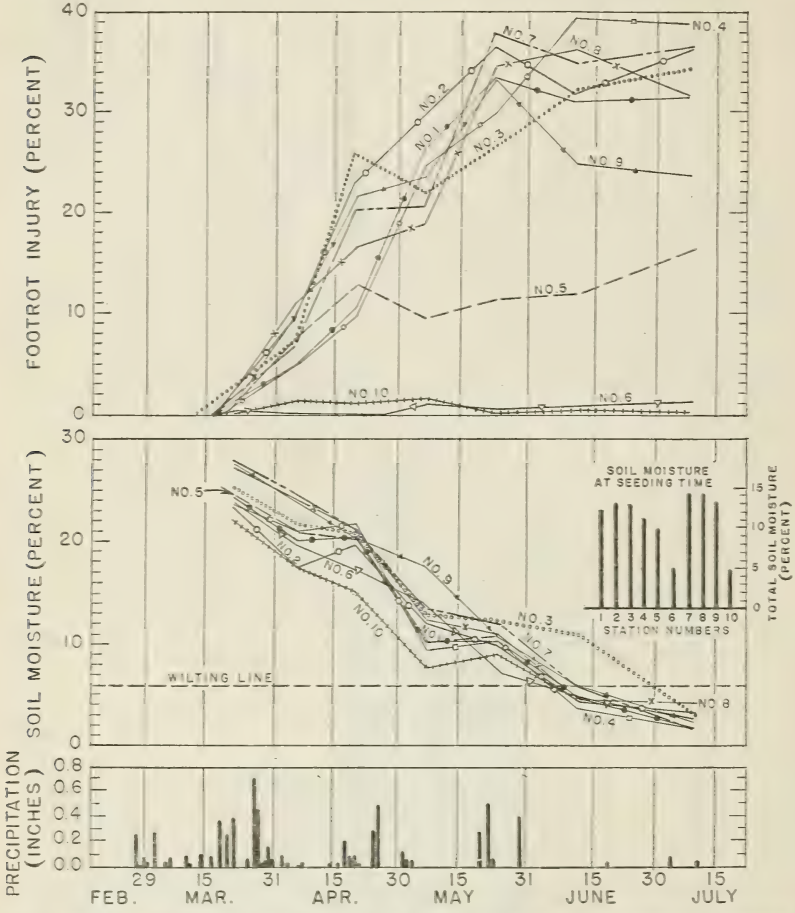


FIGURE 5.—Seasonal progress of cercosporella foot rot, soil-moisture percentages at different numbered soil-moisture stations, and precipitation in an infested field on High Prairie, Klickitat County, Wash., in 1932. Note that there is not much difference in the amount of soil moisture in the various stations during the spring, but that stations 6 and 10 (white soil phase) had very little soil moisture at seeding time. Observe also that the foot rot ceased to develop after the soil moisture dropped to near the wilting point.

soil phase.[2] In the lighter soil wheat usually does not emerge until the fall rains moisten the soil.

As shown in figure 5, the indications are that cercosporella foot rot practically ceases to develop when the available soil moisture approaches zero. The figure also shows the influence of rain on the percentage of soil moisture in the critical top 3 inches of soil, the

[2] Tests run by G. O. Baker at Washington State College show that the dark phase has a good quantity of humus and a light phase, which belongs to the subsoil, has only a fair quantity of humus.

amount of available soil moisture depending almost entirely on local rainfall after the winter accumulation of soil moisture has disappeared.

GREENHOUSE STUDIES

Two experiments were conducted in a greenhouse at Corvallis to determine, under partially controlled conditions, the effects of different soil moistures on the development of cercosporella foot rot. One series was conducted in the late winter and spring of 1931 and the other in the winter of 1931–32. In both experiments, Newberg sandy loam soil and Hybrid 128 wheat were used. In the inoculated series in each experiment, the seed when sown was inoculated with pure cultures of *Cercosporella herpotrichoides* and the greenhouse kept cool and moist, as previously described (*15, p. 8*). Percentage injury was estimated by the use of a sliding scale as follows: Healthy, no injury; slight, 10 percent injury; moderate, 30 percent injury; severe, 50 percent injury; very severe, 80 percent injury; dead, 100 percent injury.

This system, a modification of the field scale (*15, p. 8*), was found satisfactory during the experiments conducted on soil moisture in the greenhouse in 1931, but the sliding scale was modified to some extent in later studies.

In the first experiment, 8-inch drainage tiles were used for soil containers. These were filled with soil and used in two series of four tiles each; one series was not inoculated, and the other was inoculated with *Cercosporella herpotrichoides* at seeding time in the usual way. When the experiment was started the soil was uniformly and only moderately moist. The differences in soil moisture were obtained by adding water at different intervals. In each series the water was added at the rate of one-half pint for each tile container. The experiment was started January 13 and terminated April 16, 1931. The results given in table 2 are averages of four replications.

TABLE 2.—*Effect of different frequencies of watering on the severity of the cercosporella foot rot on Hybrid 128 wheat plants*

[Seeded and inoculated Jan. 13, 1931. Data taken Apr. 16, 1931, Corvallis, Oreg.]

Frequency of watering [1]	Relative soil moisture conditions	Plants not inoculated [2]	Culms on plants inoculated, showing indicated severity of infection							Percentage injury
			Healthy	Slight	Moderate	Severe	Very severe	Dead	Total	
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	
Daily	Near saturation	30	24	10	19	13	4	0	70	23.4
Every second day	Abundant	46	25	4	11	21	6	2	69	30.4
Every fourth day	do	45	22	8	3	2	4	7	46	28.0
Every seventh day	Moderate	39	27	2	3	2	2	1	37	12.7
Every twenty-first day	Moderate to dry	41	29	7	2	2	0	2	42	10.2
No water added after seeding.	Eventually very dry.	42	39	6	0	0	0	0	45	1.3

[1] Rate of one-half pint per 8-inch drainage tile. [2] All plants remained healthy.

The results of this experiment indicate that *Cercosporella herpotrichoides* was most active in a soil having an abundance of moisture.

The injury to wheat grown in the nonwatered tile occurred during the first 2 months of the experiment while the original soil moisture was still sufficiently abundant to permit initial infection.

In the other experiment known percentages of soil moisture were used, and the wheat was grown in 8-quart galvanized sheet-metal pails. After seeding, the pails were covered with paraffined cloth until the wheat emerged. Water was introduced into the soil by means of long-neck funnels at various levels in an effort to distribute the moisture as uniformly as possible. As shown in figure 6, the optimum available soil moisture for the development of the foot rot in Newberg sandy loam was 16 percent. The fungus was able to make some prog-

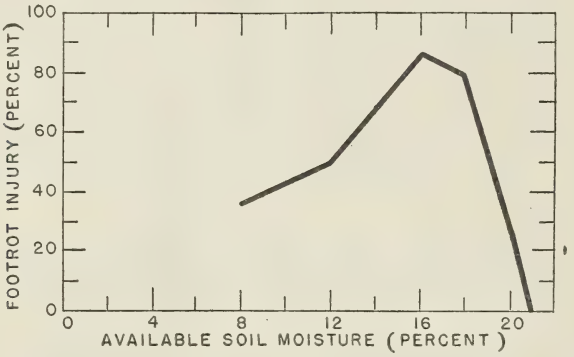


FIGURE 6.—Percentage injury to Hybrid 128 wheat inoculated with *Cercosporella herpotrichoides* at seeding time and grown in the greenhouse in Newberg sandy loam held at different percentages of available soil moisture, Corvallis, Oreg., 1931–32.

ress almost up to the saturation point of 21 percent available soil moisture, but it did not thrive above 18 percent.

AERATION AND HUMIDITY STUDIES

The moist blanket of air next to the ground line is an important factor in the development of cercosporella foot rot. The relative humidity of this portion of the plant's environment depends largely on the amount of moisture in the soil. Therefore, the data on aeration and humidity merge with those on soil moisture and must be considered with them.

It has been observed that high winds, which frequently follow spring rains in eastern Oregon and Washington, dry the ground and retard the progress of the disease. The edges of fields, which usually dry out soon after a rain, are always free of foot rot. In varietal tests it is always necessary to sow several buffer rows around the outer portions of the plot because these exposed rows are almost free from the disease.

Following the epiphytotic of cercosporella foot rot in 1927–28, there were 3 years (1928–29, 1929–30, 1930–31) in which the precipitation was considerably lower than average. During these years it was possible to reduce materially the humidity in portions of fields by thinning the wheat. The results of such an experiment are given in table 3.

TABLE 3.—*Effect of thinning plants on development of cercosporella foot rot in Hybrid 63 wheat sown in 7-inch drill rows in a field on Tygh Ridge, Oreg., on Sept. 1 and emerged Sept. 12, 1929*

[Data taken by culm count of rows 64 feet long, June 10, 1930]

Row no.	Amount of thinning	Diseased culms
		Percent
1 to 3	None removed	64.4
4	50 percent of plants removed	63.6
5 to 7	None removed	55.3
8	75 percent of plants removed	33.0
9 to 12	None removed	67.0
13	All removed except 1 plant per linear foot	40.3
14	None removed	65.0
15	do	82.6
16	do	43.0
17 to 18	All removed	
19	All removed except 1 plant per linear foot	7.2
20 to 21	All removed	
22 to 24	None removed	41.7
25 to 26	All removed	
27	None removed	43.3
28 to 29	All removed	
30	None removed	52.3

It is evident from the data in table 3 that extreme thinning, as in rows 17 to 21, inhibited the development of the foot rot to a considerable extent, presumably by favoring such aeration as to lower the relative humidity around the bases of the plants and render conditions unfavorable for the optimum development of the fungus.

Late in October 1929, another experiment was started on Tygh Ridge in which wheat straw was placed to a depth of 4 inches around the young Hybrid 63 plants that had emerged in mid-September. The ground was known to be heavily infested with *Cercosporella herpotrichoides*. The soil was very dry, and the wheat was already suffering from drought. Comparatively little snow or rain fell the ensuing winter, and in the spring the soil under the straw was still dry. Part of the straw was removed March 18, 1930, and placed around plants that had passed the winter exposed. This straw was then left in place until the final records were taken. The exposed soil was moderately moist at the time. Data on the severity of the foot rot were taken April 25, June 11, and July 10 and are presented in table 4. The results show that the straw applied in the fall kept the soil dry, as compared with the portion of the field adjacent to the experiment, and prevented the foot rot from developing to any extent. On the other hand, the straw applied on moist ground in the spring subjected the plants to a prolonged moist period favoring foot rot and reduced evaporation from the soil during the dry, late season.

TABLE 4.—*Influence of straw mulches on the development of cercosporella foot rot on Tygh Ridge, Oreg., 1929–30*

Treatment	Culms showing foot rot—			Fallen culms, July 10
	Apr. 25	June 11	July 10	
	Percent	*Percent*	*Percent*	*Percent*
Straw applied Oct. 23, 1929	2.1	6.7	18.8	4
Control (no straw)	68.3	47.5	57.5	10
Straw applied Oct. 23, 1929, and removed Mar. 18, 1930		8.5	24.6	6
Control (no straw)		47.5	77.0	20
Straw applied Mar. 18, 1930		100.0	96.2	90
Control (no straw)		90.0	77.5	30

In later trials under more nearly average conditions, where straw was distributed in the fall on moist ground, between the wheat rows, the disease was more severe the following spring than where no straw had been applied.

Fellows[3] reported that in one experiment in cercosporella-infested ground in the Grande Ronde Valley in 1923–24, the heavier the seeding the higher the percentage of diseased plants. He states that—

> that portion of the plot which was seeded to 5 pecks per acre showed 15.9 percent diseased plants, 3 pecks per acre 1.3 percent, while 2 and 1 pecks per acre showed no signs of the disease.

He also mentioned that foot rot was not particularly abundant that year.

The effect of aeration brought about by wind on retarding the progress of the disease is illustrated in an experiment conducted in the greenhouse at Corvallis during the winter of 1931–32. Hybrid 128 wheat was grown in Newberg sandy loam soil in boxes having a cubic-foot capacity, inoculated in the usual way at seeding time, and kept watered so as to give approximately 16 percent available soil moisture. After the plants had emerged, one series of three boxes, series 1, was placed in front of an electric fan and another set of three boxes, series 2, was kept at a distance under otherwise identical conditions. Both series were watered every 3 days and the fan was run for 24 hours after each watering and so directed as to throw a current of air continuously on series 1. Foot rot developed in both series but more severely in series 2. A number of plants in series 1 died from foot rot and desiccation while very young. In series 2 the foot rot continued to develop until harvest, while in series 1 it ceased to develop soon after the experiment was started. In series 1 the ground was thoroughly dry to a depth of an inch or more soon after the fan was turned on; in series 2, the surface soil was moist all the time. At harvest the plants in series 1 showed 17.2 percentage injury from foot rot, whereas those in series 2 showed 41.6 percentage injury. These results indicate that aeration not only checks the development of foot rot, but also tends to hasten the death by desiccation of culms weakened by the disease.

In the seasons of 1932–33 and 1933–34, the comparative relative humidity at the plots on High Prairie, Wash., and at The Dalles (1932–33) and Moro, Oreg., (1933–34) were obtained by self-recording hygrographs. The results indicated that the period of relatively low humidity, which comes with the end of the spring rains, occurs several weeks earlier at Moro and The Dalles than at High Prairie, thus limiting the length of the period favorable for development of foot rot.

It was indicated in the hygrograph charts that the high humidity of the night (frequently 100) in the prairie country is counteracted by the drying winds of the day so that the fungus must depend on frequent and timely rains for its development in the spring. The fact that the precipitation on High Prairie is nearly twice as great as at Moro and 50 percent greater than at The Dalles accounts for the presence of foot rot on High Prairie and not at the two drier locations. Therefore, in these latter locations the daily relative humidity

[3] Unpublished report in files of Division of Cereal Crops and Diseases.

is of significance only as it relates to the available soil moisture, which is itself correlated with seasonal rainfall.

TEMPERATURE STUDIES

In the present investigations studies were made on the effects of air and soil temperatures on the development of the disease and also on the effects of air temperatures on the growth of *Cercosporella herpotrichoides* in pure culture.

AIR TEMPERATURES

A number of experiments were conducted in the greenhouse at Corvallis for the period from 1929 to 1932, to determine the effects of different air temperatures on the development of the disease.

During the winter of 1929–30 three varieties of wheat were grown in greenhouse flats 4 to 6 inches deep. Some of the seed was not inoculated and some was inoculated at seeding time, as previously described (*15*). Some of each of the inoculated and noninoculated flats were kept in a cool, humid greenhouse at a temperature of 45° to 60° F., throughout the experiment, and the others were kept in a warm, humid greenhouse at about 75°, for the first 3 weeks and then transferred to the cool greenhouse. Disease readings were taken when the wheat was in the soft-dough stage, and the percentage of infected culms is given in table 5.

TABLE 5.—*Percentage of infected culms of 3 varieties of wheat grown under different treatments at Corvallis, Oreg., 1929–30*

Variety	Infected culms from plants grown—			
	Continuously in cool greenhouse		In warm greenhouse for first 3 weeks	
	Not inoculated	Inoculated	Not inoculated	Inoculated
	Percent	*Percent*	*Percent*	*Percent*
Jenkin	0	93.7	0	41.8
Hybrid 128	[1] 18	100.0	0	61.7
Goldcoin × Pacific Bluestem (Union 27 S. B.)	0	47.2	0	8.3
Average	6	80.3	0	37.2

[1] Infection from secondary spread from nearby inoculated plants, spores being carried by splashing water when inoculated plants were watered.

During the winter and spring of 1930–31, a number of similar experiments were conducted under semicontrolled conditions. The methods used were similar to those employed the preceding years, except that the disease data were recorded by the method previously mentioned (p. 9) for estimating percentage injury. The results obtained in one of these experiments are given in table 6.

TABLE 6.—*Estimated percentage injury from Cercosporella herpotrichoides on different varieties of inoculated wheat when grown at different temperatures in the greenhouse at Corvallis, Oreg., Jan. 23 to May 13, 1931*

Variety	Culms and percentage injury at—					
	40° to 65° F.[1]		70° F.[2]		70° to 75° F.[3]	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Federation	66	29.2	59	19.8	39	0.0
Hybrid 63	156	34.3	183	18.8	139	.0
Turkey	251	40.0	285	26.2	246	1.0
Average	157	34.5	175	21.6	141	.3

[1] Relative humidity 85 to 90 percent.
[2] Relative humidity 80 to 85 percent.
[3] Relative humidity 80 to 90 percent.

During the winter of 1931–32 an experiment was conducted in which the wheat was sown and inoculated January 15, 1932, in cubic-foot boxes and incubated in glass chambers, 24 by 24 by 30 inches, unheated, or heated to certain temperatures by thermostatically controlled, frosted, electric light bulbs. One of these chambers (no. 1) was kept, unheated, out of doors; another (no. 2) was kept, unheated, in the greenhouse; and the other three were kept in the greenhouse and their temperatures regulated as follows: No. 3, 60°; no. 4, 67°; and no. 5, 75° F. The relative humidity in each chamber was maintained at about 95 percent, as shown by relative humidity indicators. The unheated chamber (no. 2) in the greenhouse was given the same lighting as those that were heated by electric-light bulbs (nos. 3 to 5). The plants in the chambers kept at the higher temperatures grew abnormally rapidly and formed crowns above the surface of the soil. Seven weeks after seeding the plants in these boxes were reinoculated and an additional inch of soil was added to cover the crowns so that crown roots could be formed. The plants were dug and the disease data taken on March 15, 3 months after seeding. A summary of the results is given in table 7.

TABLE 7.—*Injury from Cercosporella herpotrichoides on Hybrid 63 wheat plants inoculated at seeding time and grown in special chambers at Corvallis, Oreg., during the winter of 1932*

Chamber no.	Temperature	Height of plants at end of experiment	Culms	Percentage injury
	° *F.*	*Inches*	*Number*	
1	[1] 20–50	8	36	7.2
2	[2] 40–65	18	60	35.3
3	60	30	38	6.0
4	67	34	55	1.8
5	75	25	58	0

[1] Average, 44.9°.
[2] Average, 51.4°.

In the course of this experiment it became evident that the disease reactions in the different chambers were scarcely comparable because the plants in chamber no. 1, which was kept out of doors, developed so much slower than those in the other chambers.

In order to overcome some of these difficulties another experiment was conducted in the spring of 1932 in which naturally inoculated wheat plants were transplanted March 20 from an infested field on High Prairie, Wash., to Newberg sandy loam soil and placed in each of the chambers used in the experiment described above. When transplanted, about 5 percent of the plants showed natural infection with *Cercosporella herpotrichoides*. The chambers were run under the same conditions and approximately at the same temperatures as in the preceding experiment. Data were taken on the plants in the chambers April 18 and on those in the field April 19, 1932. The results are given in table 8.

TABLE 8.—*Injury from Cercosporella herpotrichoides on naturally inoculated Hybrid 128 wheat plants transplanted from an infested field on High Prairie, Wash., to chambers held at different temperatures at Corvallis, Oreg., Mar. 20, 1932*

Location	Temperature	Plants at end of experiment		Culms	Percentage injury
		Stage	Height		
	°F.		*Inches*	*Number*	
Field	[1] 30–71	Shooting	14	191	24.1
Chamber no. 1	[2] 29–74	do	18	47	28.9
Chamber no. 2	[3] 45–75	do	20	59	20.8
Chamber no. 3	60	do	24	55	17.2
Chamber no. 4	67	Early boot	27	48	10.2
Chamber no. 5	75	Heads emerging	23	39	8.4

[1] Mean, 45.2°. [2] Mean, 50.8°. [3] Mean, 57.0°.

While the increasing sunshine in the spring at Corvallis made the thermostatically controlled temperatures in the chambers only approximations, the influence of higher temperatures in checking the amount of infection is clearly evident.

SOIL TEMPERATURES

During the winter of 1932–33 two series of experiments were conducted at the Arlington Experiment Farm, Arlington, Va., to determine the influence of different soil temperatures on the development of cercosporella foot rot. Both series were conducted in the soil-temperature tanks described by Leukel (*8*), who materially aided in the progress of this phase of the work.

The first series was started October 22, 1932. Hybrid 128 wheat was planted in 24 galvanized cans in a mixture of two-thirds river sand and one-third loam. This soil mixture had a water-holding capacity of 20 percent and was maintained at 50 percent of its capacity. After planting, the cans were placed on a greenhouse bench. On December 1, the plants were in the second or third tiller stage and averaged 8 inches in height. At that time all plants were inoculated with the usual wheat-grain inoculum placed against the base of the culms and lightly covered with moist soil. Four cans were then placed in a soil-temperature tank at each of the following approximate temperatures: 5°, 10°, 15°, 20°, 25°, and 30° C. After the cans had been placed in the tanks, all plants were given artificial light from 4 p. m., until midnight each day. The average air temperature of the greenhouse throughout the experiment was 16.5° C. (62.7° F.) As the greenhouse where the tanks were placed had insufficient humidity

for satisfactory development of cercosporella foot rot, one tank at each temperature was covered on January 4 with a tightly fitting celloglass frame with a removable cover, and the plants were then reinoculated. On January 9 the plants were showing definite indications of insufficient light and the covers of the frames were removed; on January 15 the plants were covered with ordinary window glass and they developed satisfactorily from then on. The experiment was terminated and data were taken on February 6, 1933. The results are summarized in table 9.

TABLE 9.—*Average injury from Cercosporella herpotrichoides on Hybrid 128 wheat plants artificially inoculated and grown in the greenhouse, at the Arlington Experiment Farm, in soil held at different temperatures, 1932–33*

Temperature and deviation			Height of plants at end of experiment when sown—		Percentage injury
Water in tanks	Soil in cans	Air 8 inches above soil line	Oct. 22	Nov. 8	
°C.	°C.	°C.	*Inches*	*Inches*	
5.2±1.5	6.1±1	13.5±4	12.5	7.5	16.8
9.9±1	10.3±1	15.4±5	17.5	12.4	21.6
15.6±2	15.5±2	16.7±5	17.0	15.0	7.3
20.0±5	19.3±2	18.4±6	15.5	18.0	1.6
25.0±1	24.2±1	21.0±6	17.0	15.5	.0
30.2±5	28.8±3	21.5±7	15.5	14.0	.0

In the second soil temperature series, which was started November 8, 1932, Little Club wheat was grown in a manner similar to the first series described above, except that the celloglass frames over the tanks were not used and the 30° C. temperature was omitted. The height of the plants and the percentage injury from *Cercosporella herpotrichoides* at each temperature are shown in table 10.

TABLE 10.—*Average injury from Cercosporella herpotrichoides on Little Club wheat plants artificially inoculated and grown in the greenhouse at the Arlington Experiment Farm in soil held at different temperatures, 1932–33*

Approximate soil temperature (° C.)	Height of plants	Percentage injury
	Inches	
5	5.5	1.1
10	24.0	8.2
15	21.0	7.6
20	23.0	2.9
25	21.0	.7

Humidity conditions were less than optimum for the development of the disease in this experiment.

Both of these experiments indicate that the optimum temperatures for the growth of the organism in the host is approximately 10° C. The fungus is able to thrive, however, at temperatures as low as 6° and is distinctly retarded at temperatures above 15°.

INFLUENCE OF TEMPERATURE ON RATE OF VEGETATIVE GROWTH OF CERCOSPORELLA HERPOTRICHOIDES IN PURE CULTURE

The fungus was grown on commercially prepared potato dextrose agar (pH 5.5) according to standard methods and incubated in closed containers at controlled temperatures. The results, which are illustrated in figure 7 and which are the averages for several replications, show that the optimum temperature for vegetative growth in pure culture is 20° to 21° C., the minimum at least as low as 4°, and the maximum 30°.

EFFECT OF FREEZING TEMPERATURES

Preliminary studies to determine if freezing temperatures had any appreciable effect on the susceptibility of the plants to foot rot were conducted at Arlington Farm in equipment designed and operated by H. H. McKinney for special studies of wheat plants. Hybrid 128 was grown in a mixture of sand and loam, as used in the soil-temperature series. The soil containers were 8 by 8 by 8 inches with galvanized-iron sides and cypress-wood bottoms. There were 48 of these boxes of which 24 were inoculated at seeding time, November 11; 12 were inoculated on January 23 by placing the inoculum against the base of the culms and covering with soil; and 12 were not inoculated. One-half of each of these three lots was left in the cool (zero to 25° C., mostly 5° to 18°) and humid greenhouse, which was held mostly about 95 percent relative humidity. The other 24 boxes were divided into 6 lots of 4 each, consisting of 2 boxes inoculated on November 11, 1 inoculated on January 23, and 1 not inoculated. These 6 lots were frozen on separate dates as follows: (1) Just before the wheat emerged on November 21; (2) at emergence on November 23; (3) December 1; (4) January 3; (5) January 10; and (6) January 20.

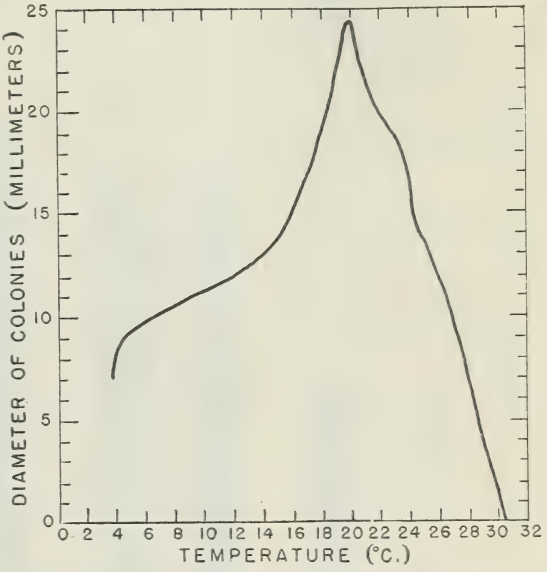


FIGURE 7.—Diameter of colonies of *Cercosporella herpotrichoides* after 8 days' growth on potato dextrose agar at different temperatures.

The soil in the boxes to be frozen was nearly saturated and four boxes at a time were placed in the insulated electric refrigerator surrounding freezing-coil units. The temperature was maintained at close to −3° to −2° C., there being some fluctuation. As the freezing units caused serious desiccation, temperatures below −3° proved fatal to a high percentage of the plants and even at −3°, the shock to the plants was the probable equivalent of far colder weather in the field.

After freezing, the boxes were again heavily watered and returned to the cool greenhouse.

There was insufficient material to give specific comparative data on the influence of freezing on the plants and the progress of the disease after freezing. Since the immediate purpose of the study was to determine in a general way the influence of low temperatures on the progress of the disease, the data from all of the lots were grouped together and summarized in figure 8. The percentage of injury from foot rot

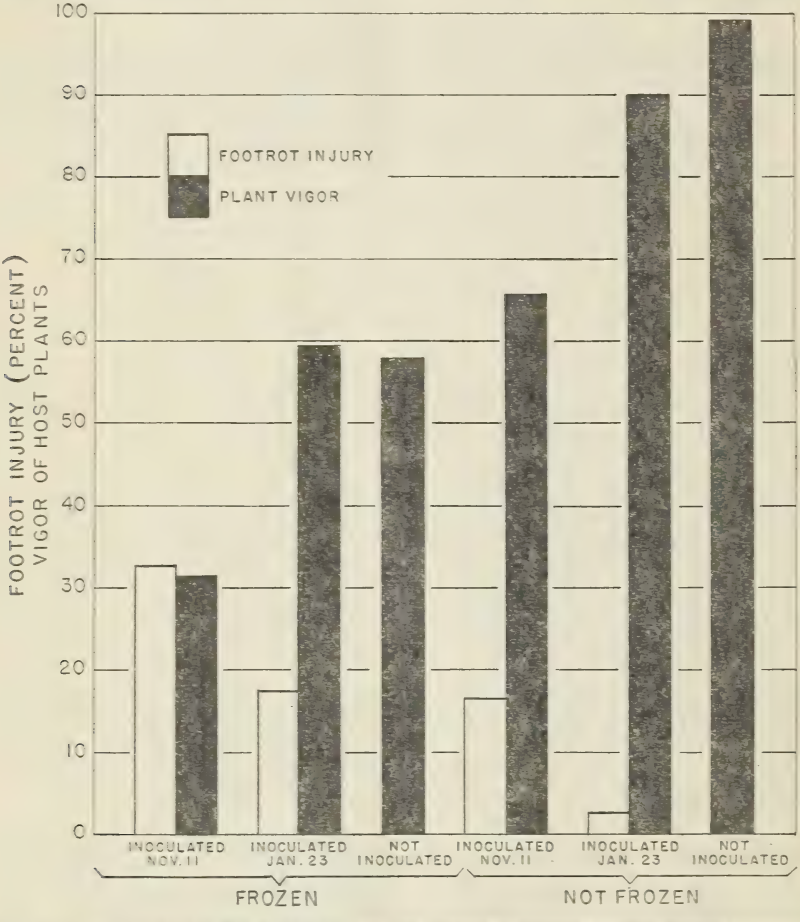


FIGURE 8.—Influence of subjecting the host to artificially induced subfreezing temperatures and the resulting effect on the progress of cercosporella foot rot. Sown November 11, inoculated November 11 in part and January 23 in part. Harvested Feb. 3, 1933.

was determined in the usual way. The vigor of the plants was arbitrarily rated on a scale of 0 to 100, 0 being used when all plants were dead; 100, when all plants were vigorous; and the intervening numbers for the conditions between these extremes.

The data in figure 8 show that the freezing increased the injury from foot rot. The type of lesion produced in the frozen inoculated wheat was similar to that occurring in the early season in the field in the small, weak, winter-injured tillers. It appears, therefore, that the

fungus is able to develop early in the season in the weakened culms and increase the amount of inoculum which later attacks the more vigorous culms.

EFFECT OF LIGHT ON DEVELOPMENT OF THE DISEASE

It has been suggested by observers that etiolation may increase the susceptibility of host plants to *Cercosporella herpotrichoides*. Two experiments were conducted, one in 1931 and the other in 1932, to determine if supplementary light had any appreciable effect on the susceptibility of the plants to foot rot.

Seed of several varieties of wheat was sown in the greenhouse at Corvallis, January 31, 1931, in cedar boxes 12 inches square and 12 inches deep. There were 2 rows of 13 kernels each in each box. The plants were inoculated in the usual way. The plants in some of the boxes were given supplementary lighting with 200-watt electric light bulbs under dome reflectors 36 inches above the plants, from 5 p. m. until 8 a. m. daily during the course of the experiment, while the others received only daylight. The experiment was terminated and the data were taken April 16, 1931. The results are given in table 11 together with those of a similar experiment conducted in 1932.

The results of the first experiment indicate that the plants that were grown with supplementary light, and which grew faster than those given only normal daylight, were the more susceptible, except possibly Hybrid 63, which was variable in its reaction to *Cercosporella herpotrichoides* under the lights. In 1932, one set of plants of each variety grown in daylight only was left growing some time after the others had been harvested. When this set had reached approximately the same stage of maturity as those under the lights they were harvested and final records were taken. The second experiment was started February 1, 1932, in artificially inoculated soil and continued until May 5, at which time one set of varieties grown in daylight only, and the set grown with supplementary light were harvested and data were taken. Another set grown in daylight was continued until May 31, at which time the plants were harvested and data taken. The results from this later experiment indicate that supplementary light has little or no effect on the progress of the disease other than advancing the maturation of the host; that is, the faster the grain approaches maturity the sooner it falls prey to the fungus.

While, in theory, it might seem reasonable to assume that etiolated plants that have been forced in midwinter by unseasonably warm weather, such as during the year 1933–34, would be less resistant to *Cercosporella herpotrichoides* than plants given supplementary light with the same conditions otherwise, this has not been borne out by the experimental data. The susceptibility of plants forced in winter must be attributed to an increased succulence and over-development owing to excess moisture and temperature rather than reduced light.

INFLUENCE OF DATE OF SEEDING ON FOOT ROT

It has been mentioned that cercosporella foot rot is most serious in regions where early fall seeding is practiced. In the Columbia Gorge section, seeding is commonly done between September 1 and 10; in the Grande Ronde Valley, between September 20 and October 10; and in the Spokane area, from about the middle of September until the first week in October. It is necessary to seed early in order to have sufficiently well-rooted plants to survive the winter months.

TABLE 11.—*Effect of supplementary light on relative susceptibility of wheat plants artificially inoculated at seeding time and grown in the greenhouse in Newberg sandy loam or grown in soil infested from previous experiments, Corvallis, Oreg., 1931 and 1932*

Year and variety	Plants grown with—								Increase (+) or decrease (−) in percentage injury with supplementary light
	Daylight only				Supplementary light				
	Culms	Height	Stage of growth	Percentage injury	Culms	Height	Stage of growth	Percentage of injury	
1931:	*Number*	*Inches*			*Number*	*Inches*			
Federation [1]	13	17.0	Boot	13.4	16	28.0	In head; falling	19.0	+5.6
Hybrid 143 [1]	10	11.5	Shooting	6.4	12	16.5	Nearly in boot	23.8	+17.4
Do	14	10.0	do	6.5	17	18.0	Nearly in head; buckling	18.5	+12.0
Hybrid 63 [1]	13	3.3	Rosette	14.0	19	6.5	Emerging from rosette	26.5	+12.5
Do	15	4.5	do	20.0	24	9.0	do	16.3	−3.7
Do	17	4.5	do	28.6	19	8.0	do	28.1	−.5
Do [2]	21	6.0	do	16.8	24	7.0	do	15.4	−1.4
Do	21	5.5	do	15.6	21	8.8	do	13.9	−1.7
Do	18	5.5	do	25.6	17	8.0	do	32.3	+6.7
Do [3]	24	4.5	do	15.6	22	9.0	do	17.6	+2.1
Do [4]	22	4.5	do	0.0	23	6.0	do	[5] 7.3	
Average	17	6.9		14.7	19	11.3		21.1	+4.9
1932:									
Galgalos [6]	36	28.0	Heading; no falling	56.6	45	30.0	Hard dough; heavily fallen	57.7	+1.1
Do [7]	36	48.0	Hard dough; all fallen	64.4					[8] −6.7
Goldcoin [6]	22	26.0	Nearly in boot	53.6	20	38.0	In dough; moderate falling	46.5	−7.1
Do [7]	22	53.0	In dough; none fallen	58.1					[8] −11.6
Hybrid 128 [6]	64	40.0	In boot; none fallen	56.6	59	48.0	Soft dough; none fallen	65.5	+8.9
Do [7]		48.0	Soft dough; half fallen						
Kubanka [6]	40	36.0	In boot or emerging; none fallen	42.0	39	30.0	Nearly mature; few fallen	61.0	+19.0
Do [7]	36	50.0	Hard dough; none fallen	68.9					[8] −7.9
Wilhelmina selection [6]	22	22.0	Emerging from boot	39.0	30	45.0		61.0	+22.0
Do [7]	26	33.0	Soft dough; not fallen	57.6					[8] +3.4
Tenmarq [6]	34	28.0	Mostly in boot; none fallen	50.0	50	46.0	Nearly mature; moderate falling	72.4	+22.4
Do [7]	54	42.0	Hard dough; all fallen	69.0					[8] +3.4
Turkey [6]	48	28.0	In boot; few fallen	76.0	40	36.0	In dough; badly fallen	78.8	+2.8
Do [7]	26	42.0		76.9					[8] +1.9
Average	36	37.4		{ [6] 53.4 / [7] 65.8 }	40	39.0		63.3	{ [9] +9.9 / [10] −2.9

[1] Grown in new soil artificially inoculated.
[2] Grown in old soil infested from previous experiments.
[3] Grown in old infested soil also artificially inoculated.
[4] Control grown in noninfested soil not inoculated.
[5] Accidentally inoculated by splashing water, therefore not included in the average nor in the "increase or decrease" column.
[6] Harvested and data taken May 5, 1932.
[7] Harvested and data taken May 31, 1932.
[8] Comparison with data from plants grown with supplementary light and harvested at a corresponding stage May 5.
[9] Average from May 5 data.
[10] Average of differences referred to in footnote 8.

As a result, if prolonged warm spells occur in the fall and winter, the plants are often far advanced in the early spring, are excessively leafy, and have relatively thin cell walls. That they are especially susceptible to cercosporella foot rot was indicated as far back as 1923 by Heald (*6*, *Bull. 180*). He made seedings at 10-day intervals from August 30 to November 1, 1922, and found that the severity of the disease ranged from 100 percent of the culms infected and 75 percent fallen at harvest, in the first seeding, to 34.4 percent of the culms infected and only about 2 percent fallen at harvest, in the seedings made October 20 and November 1. Several workers have made studies of the influence of time of seeding on the development of the so-called leptosphaeria foot rot and other foot rots. Gaudineau and Guyot (*4*) present evidence that the earlier sown grain is the most severely infected at harvest. They report the mean percentage coefficient of attack for various dates of seeding as follows: October 7, 85; October 20, 63; November 1, 54; November 15, 53; December 1, 36; December 15, 11; January 15, 9; spring-sown, 5 to 10.

They were dealing with the foot rot complex in northern France, which includes take-all (*Ophiobolus graminis* Sacc.), *Fusarium* spp., *Leptosphaeria herpotrichoides* De Not., and *Cercosporella herpotrichoides*. Parisot (*11*), who apparently holds to the theory that nutritional factors are the main cause of soil-borne foot rot diseases, states that early seeding and all those factors that tend toward abnormal forcing of growth induce infection and result in severe loss. The reports from various north-European countries are almost unanimous in declaring that the earlier the seeding the greater the chances for losses from these diseases.

In 1928 [4], two series of periodic seedings were made in infested soil; one on Seven Mile Hill, Wasco County, Oreg., and the other near Imbler, Union County, Oreg. The seedings at the former location were made by C. W. Daigh, former county agent of Wasco County, and those at the latter location by the late Robert Withycombe and his staff of the Eastern Oregon Branch Experiment Station at Union. At each of these locations four varieties (Hybrid 128, Hybrid 143, Hybrid 128×Goldcoin, and Kharkof) were sown each time. Infection data were taken by Hurley Fellows and the writer in July 1929. The results are given in table 12.

TABLE 12.—*Average percentage of culms infected with Cercosporella herpotrichoides in four varieties of wheat sown in 1928 in naturally infested soil*

Location and date sown	Culms	
	Infected	Fallen
Seven Mile Hill:	*Percent*	*Percent*
Sept. 5	24.4	2.5
Sept. 19	18.3	3.5
Oct. 4	6.7	(a)
Oct. 17	6.6	(a)
Near Imbler:		
Aug. 17	64.1	
Sept. 4	73.2	

[a] Trace.

[4] Planned by Hurley Fellows.

A similar series of periodic sowings was made in infested soil near Alicel, Union County, Oreg., and like results were obtained the following year. The sowing made September 1 gave 44 percent of infected culms; that made October 15, 32.9 percent; and that made October 20, 28.4 percent. Not only were the percentages of infected culms lower in the later sowings, but the lesions were so much smaller that the injury to the plants was conspicuously less than that on the plants from the early sowings.

It is evident from these data that wheat plants from early seedings are injured more by *Cercosporella herpotrichoides* than are those from later seedings. Because of this it has become the usual practice of the writer, in sowing wheat varietal resistance plots, to sow very early in September so as to insure sufficient foot rot for comparative studies. The plants always make a strong growth in the fall as well as in the spring and they are always the first to show foot rot in the spring. In fact, some varieties are usually so severely attacked as to be practically destroyed by the middle of May. However, the early difference in amount of foot rot is lessened as the season advances and the plants from the later seedings reach the susceptible stage. This is borne out by foot rot counts taken on High Prairie and near Imbler in 1930–31. On High Prairie the wheat varietal plots, in which Hybrid 128 was included, were sown August 31, 1930, and the adjacent general field of Hybrid 128, in which the plots were located, was sown September 8. On March 24 the wheat plants in the varietal plot were about 12 inches high, very leafy, and were beginning to show foot rot. A few feet away in the general field the plants were considerably smaller and only a trace of foot rot was evident. At Imbler similar observations were made on Goldcoin wheat sown September 6 and October 5, 1930. The seasonal progress of the disease at these two locations, as indicated by the percentage injury at different dates, was determined by the method previously described (*15, p. 8*), and is shown in table 13.

TABLE 13.—*Seasonal progress of cercosporella foot rot on Hybrid 128 and Goldcoin wheats from two dates of seeding, 1930–31*

Date of observation	Percentage injury on—					
	Hybrid 128 sown at High Prairie, Wash.			Goldcoin sown near Imbler, Oreg.		
	Aug. 31	Sept. 8	Difference	Sept. 6	Oct. 5	Difference
Mar. 24	1.2	0.3	0.9			
Apr. 11	20.0	12.8	7.2			
Apr. 18	27.1	14.2	12.9			
May 27	37.4	32.7	4.7			
July 2	38.5	37.3	1.2			
Apr. 9				8.4	1.4	7.0
May 20				26.8	4.9	21.9
July 8				49.8	38.5	11.3

These results indicate that wheat plants from late seedings may reach a physiological state for maximum infection at a period so late in the season that the crop is out of danger from serious attack by the fungus. This is further indicated by the failure of the fungus to attack spring-sown wheat as shown previously (*15, p. 10*).

CLIMATIC FACTORS IN AREAS HARBORING CERCOSPORELLA HERPOTRICHOIDES

In correlating the experimental data it is essential to make a critical comparison with gross climatic influences at representative meteorological stations in the regions infested with the cercosporella foot rot.

AVERAGE ANNUAL PRECIPITATION IN AREAS WHERE CERCOSPORELLA FOOT ROT OCCURS

Except for the statement that the disease occurs only in localities in the Columbia River Basin where the annual precipitation is between 14 and 25 inches yearly (*15*), there is no information available on the influence of moisture upon the development and occurrence of cercosporella foot rot in the United States. In a recent paper Guyot (*5*) reports that in France the development of foot rot of cereals (caused by various fungi) is favored by prolonged rains and overcast weather.[5]

Data on the average annual precipitation at stations of the United States Weather Bureau located in or adjacent to cercosporella foot rot areas in the Columbia River Basin; and on the average annual severity of the disease in the period from 1928 to 1935 in the respective areas, together with the elevation of the stations and fields, and the estimated precipitation in the foot rot areas are given in table 14.

These data indicate that cercosporella foot rot usually is most severe where the average annual precipitation approximates 16 to 22 inches. The annual precipitation is next to the lowest at Friend, Oreg. However, the vegetation at Friend, which includes *Pinus ponderosa* Dougl. and *Quercus garryana* Dougl., indicates that this locality receives, on an average, more precipitation than indicated by the records for the period 1924–32. This is borne out by the observation that Dufur, which is some miles away in a more arid and treeless section, has, since 1924, averaged approximately 2½ inches less precipitation than Friend. Since the average annual precipitation at Dufur is 13.21 inches for the 24-year period 1909 to 1932, that at Friend is estimated at almost 16 inches for an equally more representative period than the relatively dry period from 1924 to 1932. The foot rot area on Tygh Ridge lies east of Friend and several miles southeast of Dufur at a somewhat higher elevation. A standard rain gage was maintained beside foot rot infested fields on Tygh Ridge during 1932–33, and at a point 3 miles farther east in a slightly drier location from 1933 to 1935. Three years' precipitation for this and adjacent stations is given by months in table 15. The data for High Prairie also are from a standard rain gage maintained beside foot rot infested fields. These data indicate that Tygh Ridge probably receives slightly more precipitation than Dufur, where foot rot usually does not occur, and also that High Prairie receives considerably more precipitation than the nearest Weather Bureau station at Goldendale, where foot rot is usually absent except in small quantities a few miles away near Centerville, Wash.

[5] Since the completion of this study additional experimental information has been published in Europe, none of which is appreciably applicable to the local studies in Oregon, Washington, and Idaho.

TABLE 14.—*Location and average severity of foot rot in the period from 1928 to 1935 and average annual precipitation in each area estimated on the basis of precipitation at nearby U. S. Weather Bureau stations*

Weather Bureau station				Foot rot infested fields						
Location	Elevation	Years preceding 1932 covered by data	Average annual precipitation	Location	Elevation	Distance from Weather Bureau station	Estimated average annual precipitation, 1928–32	Average severity		
								1928–33	1934	1935
Idaho:	*Feet*	*Number*	*Inches*		*Feet*	*Miles*	*Inches*			
Coeur d'Alene	2,157	39	24.70	Near Coeur d'Alene	2,400	3	25	Moderate (1931)		
Grangeville	3,323	18	25.23	Near Fenn	3,200	5–10	23	None	Severe+	Trace.
Lewiston	757	32	14.50	Lewiston flats and hills	2,000+	5–15	16	Trace	do	Do.
Moscow	2,748	40	21.86	Latah County	2,748	0–15	20–22	None reported	Severe	Slight.
Nezperce	3,082	23	19.56	Near Nezperce	3,000	0–5	19–20	Trace (?)	Severe+	Trace.
Oregon:										
Dufur	1,250	24	13.21	Tygh Ridge	2,700	7	14	Severe	Severe−	Moderate.
Friend	2,400	8	13.58	Friend	2,400	0	14	Trace to none	Moderate	Slight.
La Grande	2,784	45	19.36	Alicel to Imbler	2,800+	7–10	18+	Severe−	Severe+	Severe.
Do	2,784	45	19.36	Elgin	3,200	18	18	do	Severe	Moderate.
Ortley (Seven Mile Hill).	1,600	10	21.91	Seven Mile Hill	1,600	0	22	Moderate	do	Do.
Pendleton	1,488	44	14.03	Havana (warehouse)	1,550	6–8	15–16	Trace	Slight	Trace.
Washington:										
Anatone	3,790	19	23.64	Near Anatone	3,700	2–10	21	Moderate	Moderate	
Dayton	1,700	35	21.01	East of Dayton	1,850	5	20	Slight	do	Slight.
Deer Park	2,121	21	19.69	Peone and Pleasant Prairies.	2,100	15	18–20	Severe	Severe	Moderate.
Goldendale	1,635	25	15.80	Centerville	1,600	6	15	Slight	Moderate+	Trace.
Do	1,635	25	15.80	High Prairie	1,800	16	18	Severe	Very severe	Severe.
Pullman	2,550	38	20.73	Whitman County	2,500	0–15	19–20	Trace to none	Moderate	Slight.
Rosalia	2,425	41	18.30	Rosalia, Plaza, and Fairfield	2,400–2,600	0–15	18	do	Moderate+	Do.
Spokane	1,929	52	16.66	Peone and Pleasant Prairies.	2,100	11	18–20	Severe to moderate	Severe	Moderate.
Do	1,929	52	16.66	Spokane Valley, Wash.	2,000	18	20	do	do	Do.
Do	1,929	52	16.66	Spokane Valley, Idaho	2,000+	18–30	20–22	Moderate to slight	Moderate+	Slight.
Walla Walla	991	47	17.06	East of Walla Walla	1,050	10	17	Slight+	Moderate	Do.

TABLE 15.—*Precipitation as measured by standard (U. S. Weather Bureau type) rain gages on Tygh Ridge, Oreg., and High Prairie, Wash., as compared with precipitation at Weather Bureau stations at Dufur and Friend, Oreg., and Goldendale, Wash.*

Station	Year	July	August	September	October	November	December
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Tygh Ridge, Oreg.	1932-33	0.00	0.06	0.00	1.04	2.09	1.50
Do.	1933-34	.17	.14	.87	1.09	.32	2.42
Do.	1934-35	.04	.17	.71	1.53	2.30	1.16
Average		.07	.12	.53	1.33	1.57	1.69
Dufur, Oreg.	1932-33	.00	[1] T	.00	.78	1.70	1.33
Do.	1933-34	.07	.17	1.09	.80	.52	2.73
Do.	1934-35	.00	.09	.96	1.16	2.32	1.96
Average		.02	.09	.68	.91	1.51	2.01
Friend, Oreg.	1932-33	.00	.01	.05	.52	2.72	2.00
Do.	1933-34	.20	.22	1.15	.85	.67	5.17
Do.	1934-35	[1] T	.18	1.23	2.22	3.37	2.78
Average		.07	.14	.81	1.20	2.25	3.32
High Prairie, Wash.	1932-33	.10	.06	.02	1.44	4.90	3.98
Do.	1933-34	.03	.22	1.40	2.69	1.23	11.78
Do.	1934-35	.01	.34	.70	3.09	4.30	5.68
Average		.05	.21	.71	2.41	3.48	7.15
Goldendale, Wash.	1932-33	.05	.28	.00	.89	3.31	2.14
Do.	1933-34	.03	.01	1.32	1.60	.83	7.78
Do.	1934-35	.00	.20	.50	2.16	3.12	2.62
Average		.03	.16	.61	1.55	2.42	4.18

Station	Year	January	February	March	April	May	June	Total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Tygh Ridge, Oreg.	1932-33	1.70	0.53	1.13	0.09	1.78	0.50	10.42
Do.	1933-34	1.23	.35	1.12	.96	.38	.16	9.21
Do.	1934-35	.85	.45	.74	.49	.13	.39	8.96
Average		1.26	.44	1.00	.51	.76	.35	9.53
Dufur, Oreg.	1932-33	1.00	.77	.79	[1] T	1.16	.48	8.01
Do.	1933-34	.89	.38	1.22	.77	.24	.04	8.92
Do.	1934-35	.72	.44	.52	.41	.06	.20	8.84
Average		.87	.53	.84	.39	.49	.24	8.58
Friend, Oreg.	1932-33	2.02	1.43	1.11	.11	1.44	.41	11.82
Do.	1933-34	1.28	.54	1.30	.62	.32	.05	12.37
Do.	1934-35	1.79	.76	1.00	.66	.20	.33	14.52
Average		1.70	.91	1.14	.46	.65	.26	12.91
High Prairie, Wash.	1932-33	3.85	2.66	2.12	.17	1.14	.95	21.39
Do.	1933-34	3.61	.65	2.47	.68	.36	.29	24.41
Do.	1934-35	2.94	1.05	2.03	1.26	.01	.30	21.71
Average		3.47	1.45	2.21	.70	.50	.51	22.50
Goldendale, Wash.	1932-33	2.49	1.97	1.59	.08	1.19	.61	14.60
Do.	1933-34	3.30	.66	1.77	.80	.18	.21	18.49
Do.	1934-35	1.54	.81	.98	.65	.80	.93	14.31
Average		2.44	1.15	1.45	.51	.72	.58	15.80

[1] T=trace.

The foot rot station at Havana (warehouse), Oreg., near Pendleton, probably receives from 15 to 16 inches of precipitation a year, as that at the Pendleton Field Station, 2 miles away, has, according to

G. A. Mitchell, averaged in the 3-year period from 1929–32 approximately 2½ inches a year more than at the Weather Bureau station at Pendleton, the average for which, over a period of 43 years, is 14.16 inches.

The most striking example of the association of cercosporella foot rot with certain precipitation areas is illustrated in the Columbia Gorge area centering around The Dalles. At this point, which lies just east of the Cascade Mountain range, the Columbia River has cut through a layer of basalt rock about 1,600 feet thick. The region adjacent to the gorge is a rolling plateau adapted to winter wheat and in those portions adjacent to the Cascade Range cercosporella foot rot occurs. Winter wheat is also grown on the higher and more arid land south and east of The Dalles, some fields being within a short distance of the city. This wheat south and east of The Dalles is entirely free of foot rot.

The mean annual precipitation for these regions, as shown in table 16, indicates that northwest of The Dalles, at Lyle, Wash., the average annual precipitation for the period from 1892 to 1910 was greater than at the other points on account of the influence of moisture-laden winds from the humid western portion of Oregon and Washington that pass through the gorge at higher elevations near The Dalles. For example, on Seven Mile Hill, where foot rot occurs, and across the river on High Prairie, where foot rot also is prevalent, the precipitation is distinctly greater than at The Dalles. East of The Dalles, the more arid conditions of the interior prevail. To illustrate, Big Eddy, Oreg., about 4 miles east of The Dalles, receives approximately 3 inches less annual rainfall. Moro, Oreg., still farther east, at an elevation of 1,838 feet, receives an annual precipitation of 11.14 inches and foot rot is absent. The area of foot rot infestation on Tygh Ridge, southeast of The Dalles, probably receives an average of about 14 inches of precipitation, and this, coupled with the favorable soil moisture factors previously mentioned, permits foot rot to maintain itself locally although actually beyond the usual range of the disease.

TABLE 16.—*Average annual precipitation in the Columbia Gorge section of Wasco and Sherman Counties, Oreg., and Klickitat County, Wash., and the average severity of foot rot near these stations*

Station	Elevation	Period covered by weather data	Average annual precipitation	Average severity of foot rot, 1928–32
Oregon:	*Feet*		*Inches*	
Big Eddy	123	1916–32	11.21	[1].
Moro	1,838	1909–32	11.14	None.
Seven Mile Hill (Ortley)	1,600	1912–22	21.92	Moderate+.
The Dalles	96	1892–1910	14.77	None.
Do	96	1912–22	14.31	Do.
Washington:				
High Prairie	1,700–1,800	1932–36	22.50	Severe.
Lyle (near)	600	1892–1910	25.87	[1].

[1] No winter wheat grown at this station.

The relation of average annual precipitation to the distribution of cercosporella foot rot in the Columbia River Basin is shown in figure 9.[6]

[6] This figure has been adapted from Kincer's fig. 2 (7).

It becomes evident that the most severe cases of foot rot occur in those areas having an average annual precipitation close to 20 inches. No areas in this region are known where the precipitation averages above 25 inches a year. When the average precipitation drops to 14 or 15 inches, the disease is usually of slight importance, unless soil moisture is concentrated in favored spots.

It is clear that many factors, other than average annual precipitation, influence the distribution and severity of the disease. This is

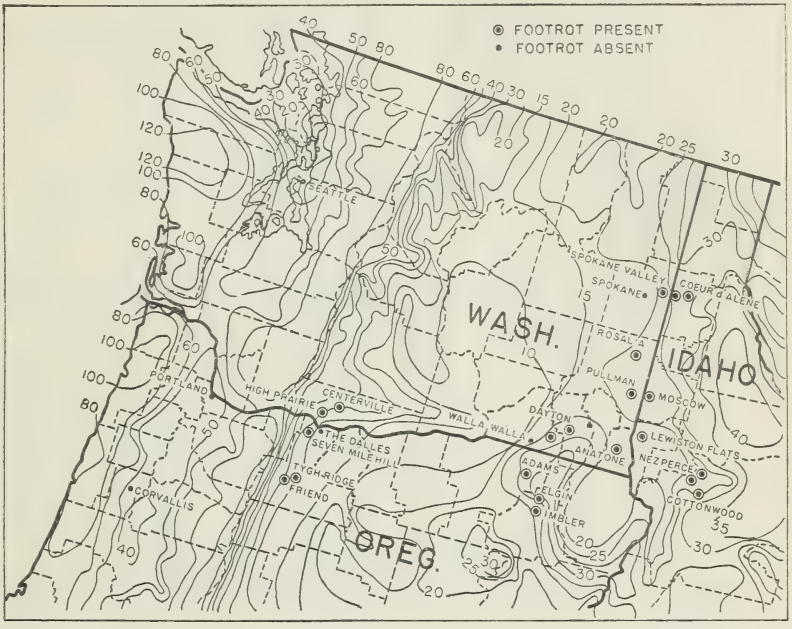


FIGURE 9.—Map showing the average annual precipitation in Washington, Oregon, and Idaho, with the general location of foot rot infested areas indicated by black encircled dots.

indicated by the great variations in its severity in regions having almost the same amount of precipitation.

INFLUENCE OF SEASONAL RAINFALL ON PROGRESS OF DISEASE

From the middle of February, or more commonly the middle of March, to late May or sometimes even later (June 1931) foot rot develops most rapidly during or immediately following abundant or protracted rains. This is illustrated in figures 3, 4, 5, and 10. In figure 10, the observations on the development of the foot rot were recorded on the basis of the number of culms infected, while in figures 3, 4, and 5 they were recorded by a method previously described (*15*) for estimating the potential injury caused by the disease. While circumstances did not permit detailed observations on exactly how quickly the fungus responded to each individual rain in the spring, indications were that the lag between the date of rainfall and the observable increase in amount of foot rot was only a few days at the most.

In the Columbia Gorge area the hot, dry summer season usually begins in May and continues with short interruptions in the form of

occasional showers, or, more rarely, heavy rains, until autumn. In the Grande Ronde Valley, Oreg., however, the rainy reason is prolonged into June, as shown by the precipitation data from La Grande (fig. 11).

During the spring and summer of 1930 cercosporella foot rot started later in the season in the Grande Ronde Valley (Alicel, Imbler, and Elgin, Oreg.) than in the Columbia Gorge area (The Dalles, Seven Mile Hill, and Tygh Ridge, Oreg., and High Prairie, Wash.) and, in

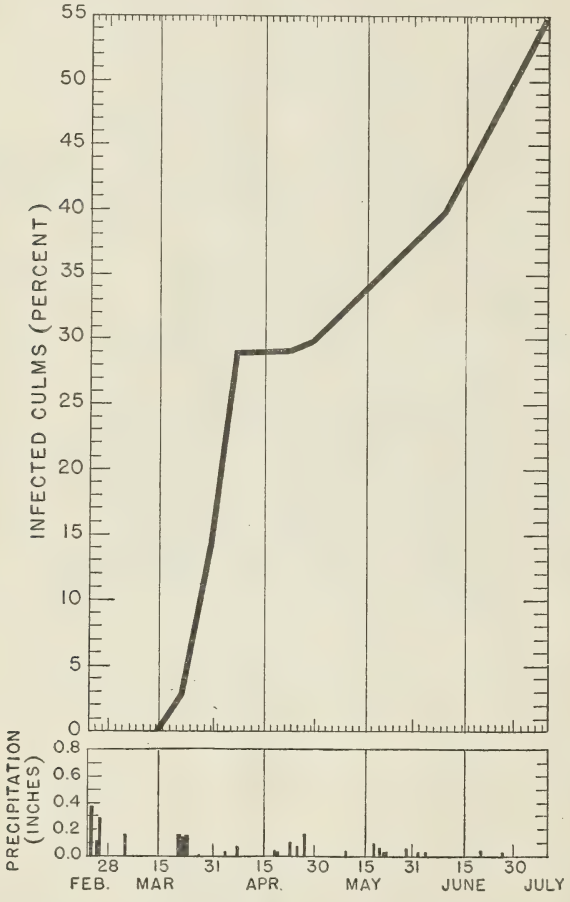


FIGURE 10.—Seasonal progress of cercosporella foot rot and rainfall on High Prairie, Klickitat County, Wash., during the spring of 1930. Precipitation data are from the Weather Bureau station at Goldendale, Wash.

the former area, it continued to progress some time after its development had ceased in the Columbia Gorge area, on account of the hot, dry conditions in the latter area (figs. 11, 12, *A*). In 1931, the monthly rainfall in the Grande Ronde Valley was not normal with respect to seasonal distribution (fig. 11), and the progress of the foot rot at Imbler during this dry spring and summer was similar to that in the Columbia Gorge area (fig. 12, *B*).

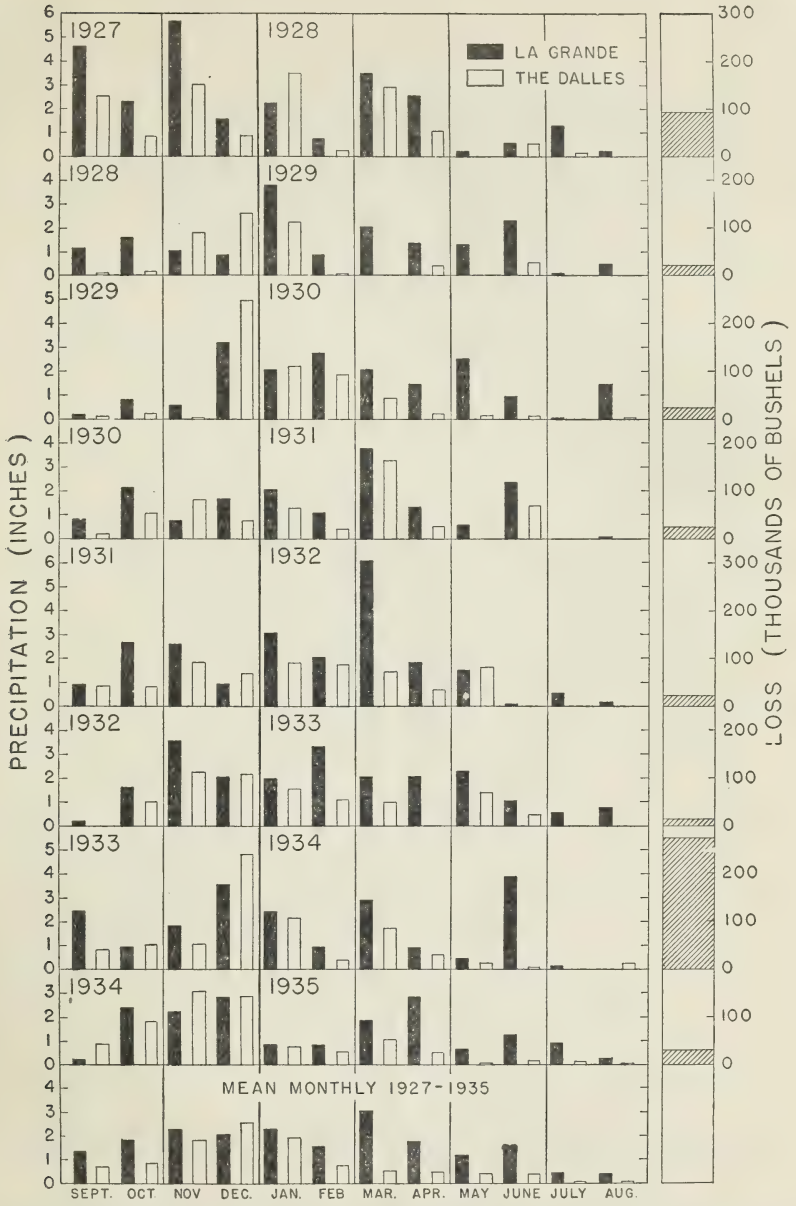


FIGURE 11.—Monthly precipitation for 1927 to 1935 at The Dalles and La Grande, Oreg., with estimated annual loss of wheat from cercosporella foot rot in the entire Columbia Basin. Note that the rainy season at La Grande is usually more prolonged than at The Dalles.

It has been found that cercosporella foot rot does not appear at the same time in all parts of an infested field. During 1930–31, for example, the disease did not show itself in some portions of the fields until after the heavy rains of mid-June (figs. 3, 4). The first culms to become infected in the early spring are small outer tillers that are

weaker and less resistant to the fungus (*15*). They serve as sources of infection and during the heavy rains the spores and portions of mycelium are carried to other culms and plants. A case was mentioned in a previous article (*15*) in which inoculum from a strip of inoculated wheat had infected the grain for several rods down hill from the original source of inoculation made the same season.

Differences in the spread of the disease in the field from focal points may be attributed, in part, to differences in the maturity of the wheat plants in various parts of the field. However, there is no

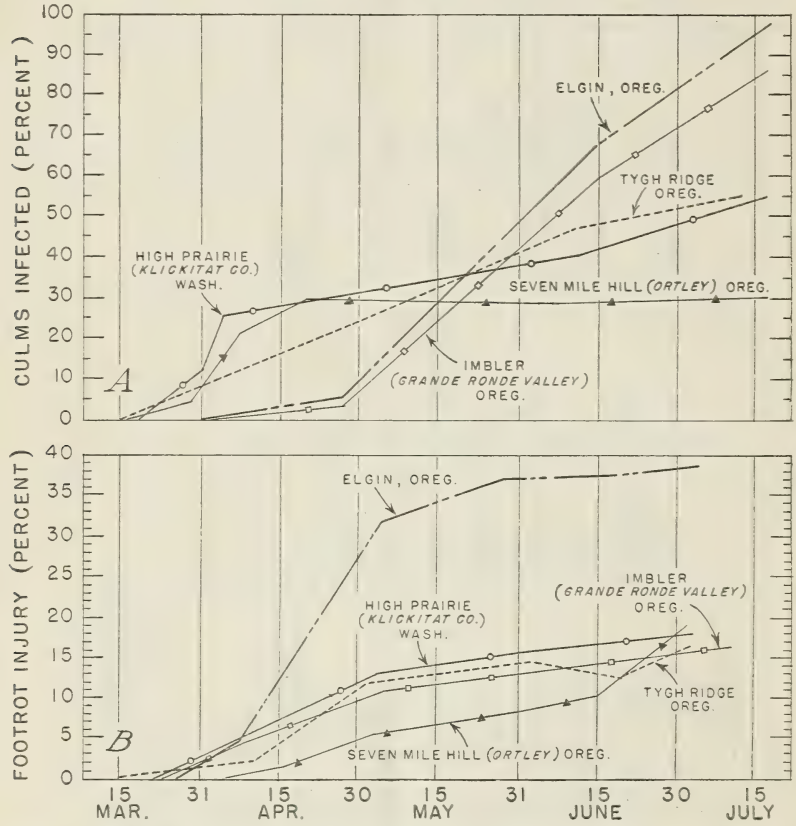


FIGURE 12.—Seasonal progress of cercosporella foot rot in various localities during 1930 (*A*) and 1931 (*B*) as based on representative fields.

question that the spread is greatly hastened by rains washing the inoculum from points of early infection.

AIR TEMPERATURES OF CERCOSPORELLA FOOT ROT INFESTED REGIONS

Air temperatures at stations in or adjacent to the foot rot infested areas have been studied and the average monthly temperatures for the foot rot season, September to June, and the average annual temperatures have been determined. These are given in table 17. Several stations in the Pacific Northwest located at some distance from the infested areas are included for comparison.

TABLE 17.—*Location and average severity of foot rot from 1928 to 1935 and average air temperatures at nearby United States Weather Bureau stations*

[Weather data from earliest records to 1932]

Weather Bureau station						Foot rot infested areas			
		Air temperature							
Location	Elevation	Annual average of monthly		Average monthly, September to June, inclusive		Location	Elevation	Distance from Weather Bureau station	Average severity
		Mean	Minimum	Mean	Minimum				
Idaho:	*Feet*	°*F.*	°*F.*	°*F.*	°*F.*		*Feet*	*Miles*	
Coeur d'Alene	2,157			43.4	33.3	Vicinity of Coeur d'Alene	2,400	3	Moderate (1931).
Grangeville	3,323	46.0		41.6		Near Fenn	3,200	0–15	Severe (1934 only).
Moscow	2,748	46.9		42.9		Vicinity of Moscow to Genesee	2,600–2,800	0–20	Severe (1934).
Nezperce	3,082	45.0		40.9		Vicinity of Nezperce	3,100	0–5	Severe (1934 only).
Oregon:									
Baker	3,471	45.4	34.5	41.3	30.7	Alicel to Imbler	2,800	43	Severe.
Big Eddy	123	54.3		50.6		Seven Mile Hill	1,600	10	Moderate +.
Corvallis	266	51.8	41.0	49.1	39.1	Columbia Gorge area	1,600–2,700	120	Severe to moderate.
Dufur	1,250	47.1	34.0	42.8	31.1	Tygh Ridge	2,700	8	Severe.
Hood River	300	50.2	39.8	46.2	37.2	Seven Mile Hill	1,600	10	Moderate +.
La Grande	2,784	48.8	36.8	44.1	33.3	Alicel to Imbler	2,800	7–10	Severe.
Moro	1,838	48.5		43.8		Tygh Ridge	2,700	22	Do.
Ortley (Seven Mile Hill)	1,600	46.9	38.6	43.6	35.5	Seven Mile Hill	1,600	0	Moderate +.
Pendleton	1,488	52.0	38.2	48.1	35.6	Havana (warehouse)	1,550	7	Trace.
The Dalles	96	52.8	41.6	49.4	38.6	Seven Mile Hill	1,600	4	Moderate +.
Washington:									
Anatone	3,790	44.6		40.6		Vicinity of Anatone	3,700	2–6	Moderate.
Deer Park	2,151	44.8	30.6	40.8	27.8	Peone Prairie	2,100	15	Severe.
Goldendale	1,635	48.8	36.3	44.9	33.5	High Prairie	1,800	15	Do.
						Centerville	1,600	4	Slight.
Lyle (near)	800	50.9	40.2	47.2	37.3	High Prairie	1,800	8	Severe.
						Seven Mile Hill	1,600	4	Moderate +.
Pullman	2,550	47.6	37.8	43.6	34.8	Vicinity of Pullman	2,500	0–15	Moderate (1934).
Rosalia	2,425	46.9		42.9		Vicinity of Rosalia and Palouse	2,400–2,600	20	None to moderate (1934).
Spokane	1,929	48.2	38.3	44.2	34.9	Spokane Valley	2,000	18	Severe.
Walla Walla	991	53.1	43.6	49.0	40.3	Vicinity east of Walla Walla	1,200+	10+	Slight +.
White Salmon (near)	1,700	45.4		42.5		High Prairie	1,800	13	Severe.

Twelve of the sixteen stations listed in table 17 that have an average temperature of 45° F. or lower for the growing season for winter wheat were in or adjacent to the foot rot infested areas. There are included only two stations, Pendleton and Walla Walla, that are near foot rot areas (although the local infestation is slight) that have an average temperature for the season above 45° F. These stations lie at somewhat lower elevations than the nearby foot rot areas and no doubt have higher temperatures than where the disease occurs. Two stations, Baker and Moro, Oreg., that are free of foot rot and have an average mean temperature below 45° F. for the growing season must be discarded from consideration, as the precipitation is too low for the development of foot rot. White Salmon is not in a winter wheat region (orchard and timbered area) and no fair test is available. While traces of foot rot sometimes occurred near Pullman, Nezperce, Grangeville, and Rosalia no serious infestations were recorded until 1934 following the record "open winter" of 1933–34. Since a large part of the Palouse soils and Idaho high prairie soils are relatively cold and heavy and the grain is sown later in the fall than in the regularly infested areas, proper conditions are not favorable for the development of the foot rot under average climatic conditions.

In general, cercosporella foot rot in the Pacific Northwest thrives in areas having an average mean temperature for the season, September to June, ranging from 40° F. (Anatone) to slightly less than 49° F. (east of Walla Walla), with the optimum usually between 42° and 45° F.

A study of weather data indicates that average annual temperatures and average annual maximum temperatures have little significance in comparing one year's foot rot situation with another. The data also show that the average monthly temperatures and the average growing-season temperatures apparently are of little value in comparing the relative severity of the disease for 1 year with that of another. Their values as indicated above are confined to aiding in determining the approximate geographic range of the disease in the Pacific Northwest.

The influence of temperature on the progress of the disease in the field is studied to better advantage from average daily temperatures than from average monthly temperatures. The records for Goldendale, Wash., which has a temperature only slightly different (slightly colder, except in midsummer) from that at High Prairie, are given in figure 13.

DISCUSSION OF CLIMATIC FACTORS AND THEIR INFLUENCE ON PREVALENCE OF CERCOSPORELLA FOOT ROT

MOISTURE RELATIONS

Studies in both field and greenhouse show that cercosporella foot rot needs abundant soil moisture for its optimum development and that it does not thrive in comparatively dry soil nor in soil in which the moisture is near the saturation point. The soil moisture available in the top 3 inches of soil is most vital to the development of the causal fungus. Other things being equal, the severity of foot rot increased with the increase in the available soil moisture up to fairly near the saturation point. The field studies show that many factors cause

differences in the severity of foot rot under identical moisture conditions in the soil.

In the semiarid wheat-growing area in which cercosporella foot rot occurs, there is vital need for conserving all possible soil moisture. Summer fallowing is universally practiced and necessary for practical wheat production. Inasmuch as field observations and controlled studies have consistently shown that foot rot prefers fine or very fine sandy loam soils in which there is a plentiful supply of soil moisture during the spring months, the foregoing statements sound somewhat paradoxical. However, it is the so-called "open winters", combined with rains in spring and early summer, that favor the development of the disease. Furthermore, *Cercosporella herpotrichoides* is a slow-growing fungus in comparison with most of the fungi associated with it. There is a possibility that the normal soil flora of the semiarid country permits the slow-growing stroma-forming *C. herpotrichoides* to thrive, whereas in areas continuously more humid it might be checked by faster growing soil organisms. A critical comparative study of the soil floras of cercosporella-infested soils and similar soils in more humid areas is needed.

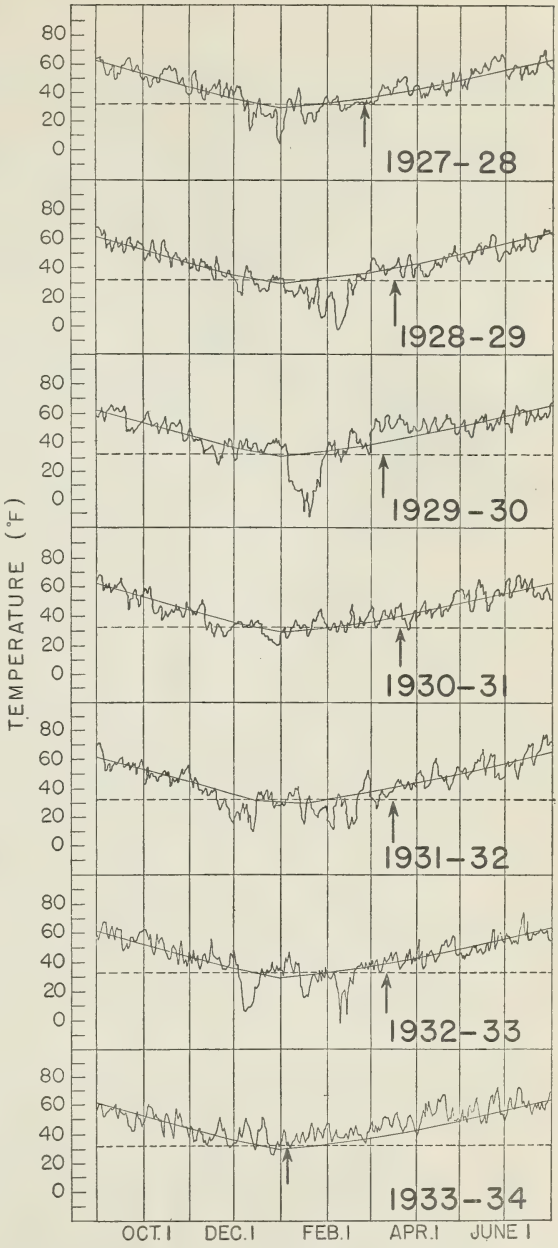


FIGURE 13.—Daily mean temperature at Goldendale, Wash., during the growing seasons (Sept. 1 to June 30) of 1927 to 1934 as compared with the 7-year average, which is represented by the smoothed line. Approximate date of beginning of foot rot injury for each year is indicated by arrow.

TEMPERATURE RELATIONS

In this disease, which attacks the wheat plants at the soil line, it is difficult to segregate arbitrarily the various components of the environment for separate observation, especially those so closely linked as temperature and moisture.

Heald (*6, Bull. 175, p. 36*) maintained that temperature was a vital factor in determining the relative prevalence of cercosporella foot rot. He stated that during the period 1921–22:

> The season was one marked by very slight rainfall and high temperatures and the foot-rot which had been so severe in previous years failed to develop. It was to be found in only slight traces in any fields.

The next year he reported (*6, Bull. 180, pp. 42–43*):

> The season was in marked contrast to that of 1922, in which no foot-rot developed. During the middle of December, 1922, there was a period of seven days with a minimum temperature below zero, while following this there was a warm period, without a snow cover during which there were eleven consecutive days when the minimum temperature ranged from 32 degrees to 52 degrees F. This period, in which the ground was never frozen and growth was stimulated, was followed in February by a second period of zero weather. During the spring of 1923 there was an abundance of rain until well toward the period of harvest. It was predicted that these conditions would be favorable to foot-rot and this proved to be true, as the disease was prevalent in all of the plots.

Hybrid 128, a one-time standard variety in the Columbia Basin, is adapted to areas having a climate similar to that at Goldendale, Pullman, and Spokane, Wash., and La Grande and Ortley (Seven Mile Hill), Oreg. The average of the mean monthly air temperatures for these stations is as follows: February, 33.1° F.; March, 40.1° F.; April, 47.8° F.; May, 53.6° F.; and June, 59.9° F. There is no information available on soil temperature at the ground line. The cercosporella foot rot, which develops best in the host (Hybrid 128) at 10° C. (50° F.) but can develop readily at 6° C. (42.8° F.) usually begins activity in March (January in 1933–34) and progresses most rapidly in April up to May. Because controlled soil-temperature experiments indicate that the disease can also make fair progress at 15° C. (59.0° F.), possibly temperature may not be the most important inhibitory factor in late season. Because high temperatures in this area usually are accompanied by reduced humidity, precipitation, and soil moisture, it is likely that moisture may be a more vital factor than temperature. However, tests with soil thermometers show that the soil-line temperature on sunny days in the spring rises at least to 40° C. (104° F.), a temperature at which cercosporella foot rot cannot thrive, even though the air temperature is below the maximum growing temperature for the fungus. Therefore, in final analysis, high temperature probably is nearly as important as deficient soil moisture in slowing up the progress of the disease in late season.

While it is evident that cercosporella foot rot attacks the wheat plants in April, when they are growing at their optimum temperature, observations indicate that if the host is not exposed to the normal increase in temperatures as it approaches heading and maturity, the fungus will rapidly increase the severity of its attack.

As is the case in many other soil-borne diseases, the optimum temperature for growth on nutrient media lies considerably above the optimum temperature for growth of the fungus in the host. However, while the fungus grows most rapidly at 21° C. it is obvious that growth at considerably lower temperatures is good and that the mycelium

is more compact at the lower temperatures and actually in better physiological condition than at 21°. The fact that the fungus can make measurable growth at temperatures slightly above freezing and is unable to grow at temperatures above 30° is in itself strong evidence that the fungus thrives best under cool conditions. Its optimum growth temperature in pure culture is only slightly higher than that of the well-known cool temperature organism, *Botrytis cinerea* Auct., and is several degrees lower than the optimum temperature for *Ophiobolus graminis* Sacc. (*2*), *Gibberella saubinetii* (Mont.) Sacc. (*3*), or *Helminthosporium sativum* Pam., King, and Bak. (*9*).

Some observers think that the cercosporella foot rot is a secondary manifestation of winter injury, while others contend that winter injury has nothing whatever to do with the malady. Because the artificial inoculation under greenhouse conditions without any subfreezing temperatures has been very successful for the writer, it is evident that freezing of the host is not necessary for heavy infection by *Cercosporella herpotrichoides*. As mentioned previously, freezing increases the susceptibility of plants, particularly early in the season. The writer is convinced that an arbitrary stand favoring low temperature injury as the primary factor or an equally arbitrary stand dismissing it entirely are not borne out either by controlled studies or by climatological field studies.

SEASONAL CLIMATE

In order to present a final summation of how the various climatic factors have operated during the several years that records have been taken, it will be necessary to give a brief chronology of these years. Fellows [7] made detailed surveys for several years before 1929 and the writer has done the same since that time (*13*). Heald (*6*) and McKinney (*10*) gave general data on the relative severity of the disease during the years 1919–24. The seasonal conditions at La Grande, Oreg., for the various years since 1927 are summarized in a very general way in table 18.

TABLE 18.—*Climatic conditions and the amount of cercosporella foot rot in Union County, Oreg., in comparison with average seasonal conditions at La Grande, Oreg.*

Year	Fall (Sept.–Nov.)	Winter (Dec.–Feb.)	Late winter and early spring (Feb.–Mar.)	Midspring (Apr.)	Late spring and early summer (May–June)	Relative severity of foot rot
1927–28	Warm and moist.	Cold	Warm and moist.	Cool and moist	Warm	Very severe.
1928–29	Warm and very dry.	do	Warm	Cool and dry	Moist	Moderate.
1929–30	Cool and dry	December warm; January partly subzero.	Warm and dry.	do	Dry	Light.
1930–31	Dry near average temperature.	Average	Average and wet.	Warm and dry.	Warm and later moist.	Moderate.
1931–32	Dry variable temperature.	Cold, later warmer.	Rapid run-off, cool and wet, later warmer.	Cool and wet, later warmer.	Dry	Moderate+.
1932–33	Warm and dry, moisture later.	Subzero freeze in December.	Cold	Cool	Cool and moist, later warmer.	Severe−.
1933–34	Warm and moist.	Warm and moist.	Warm and moist.	Warm and moist.	Warm, becoming drier.	Very severe.
1934–35	Dry and warm	Average	Warm but soil cool.	Cool and moist	Average temperature; dry.	Moderate+.

[7] Unpublished reports.

The approximate influence of the more important climatic factors is shown graphically in figure 14 for Union County, Oreg., and in figure 15 for the Palouse area. These factors are (1) growing-season precipitation (September–June); (2) precipitation in March and April; (3) accumulated degrees of daily mean temperature above freezing, September 15 (Oct. 1 for the Palouse) to March 30; and (4) accumulated degrees of daily mean temperature above freezing during November and February. The conditions necessary for severe infection are:

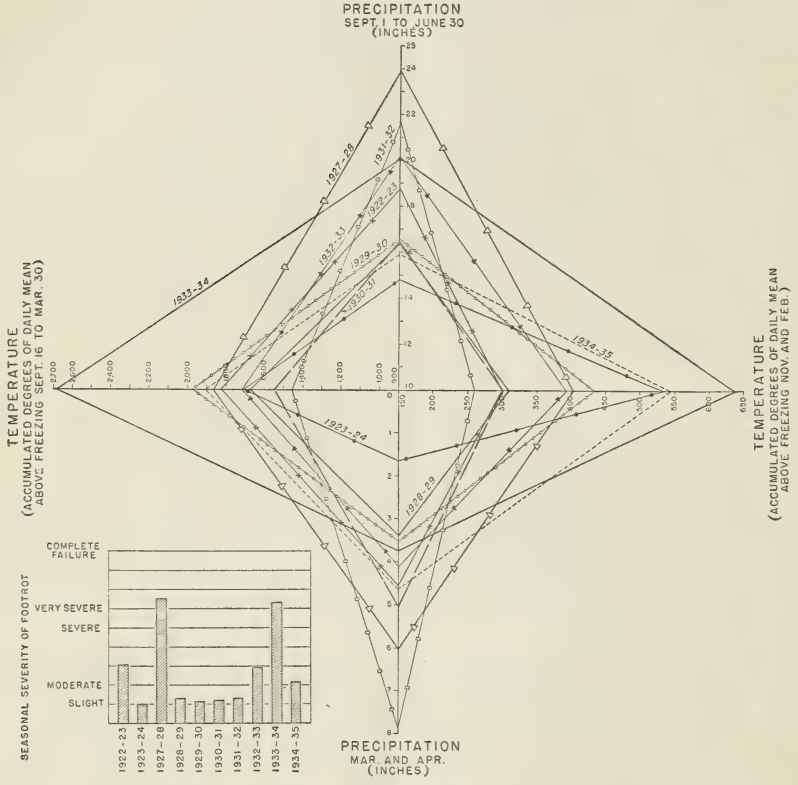


FIGURE 14.—The interrelations of four vital factors in determining the severity of cercosporella foot rot in Union County, Oreg., one of the regularly infested foot rot sections. The climatological data are taken from the records of the La Grande, Oreg., meteorological station. The areas enclosed by the lines made by connecting the points where each factor for each year occurs on the radii from the central point correlate closely with the severity of the foot rot for each season. Certain other factors, such as soil moisture at seeding time or an excess of growth-retarding days in late spring, may influence the accuracy of this correlation.

The host plant, through a sufficiently long growing season, must have reached a stage of heavy growth in the spring to become very susceptible to the invasion of the fungus. Then if there is moist, cool weather in late February, March, and April, foot rot will be destructive, especially if the backward weather is prolonged into May.

If any one of the several factors shown in figure 14 are deficient or if soil moisture is deficient at seeding time, foot rot is likely not to prove serious that season. Figure 15 indicates that foot rot is inhibited by the average severe winters and late spring seasons of the Palouse area and high prairies in Idaho, but during unseasonably warm years

such as 1927–28 and 1933–34 foot rot will occur in these colder soils. In 1934, the loss was very heavy [8] [9] in the vicinity of Nezperce, Cottonwood, and Grangeville, Idaho, a section where the disease had not been reported previously except as a trace. The following year the disease was again practically absent from the high country (above 3,000 feet elevation), but the weather had been sufficiently mild to permit a slight amount of foot rot to develop in the Palouse region

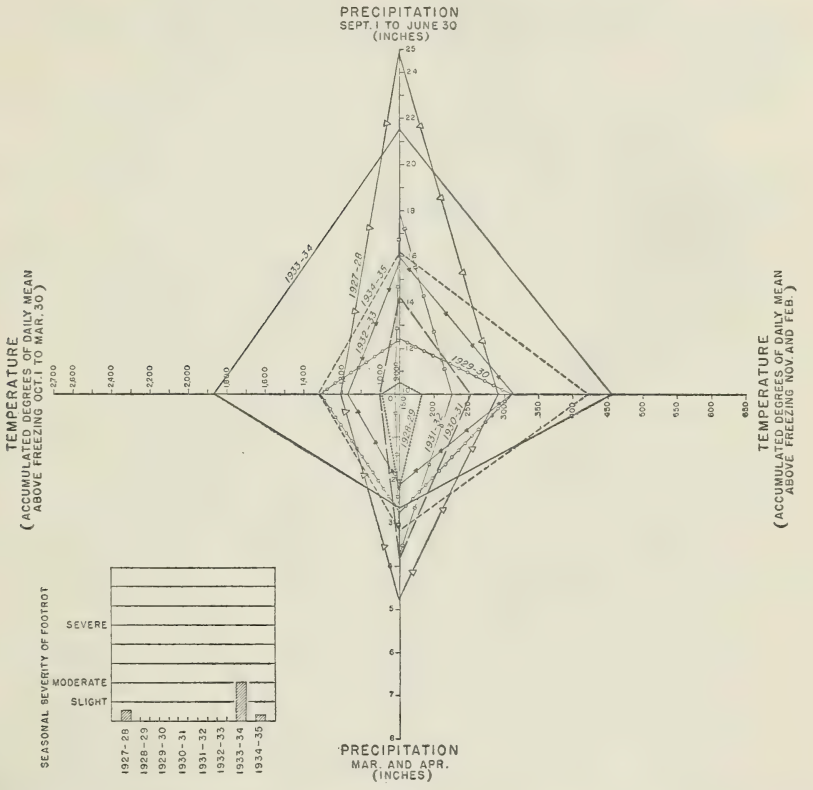


FIGURE 15.—Diagram similar to that shown in figure 14 with climatological data from the meteorological station at Rosalia, Wash., which is representative of the higher prairies (Palouse area and adjacent sections) having colder soils and which are usually free from severe foot rot injury. The necessity of warm "open winters" and early springs for optimum foot rot development is clearly indicated for such a section as the vicinity of Rosalia, Wash.

proper. It is obvious that cercosporella foot rot will be destructive to wheat growing on the heavier, colder prairie soils only under exceptionally warm, moist, and prolonged growing seasons.

SUMMARY

This circular presents results of studies conducted in the laboratory, greenhouse, and field on the influence of climatological factors on the distribution and severity of the foot rot disease of winter wheat caused by *Cercosporella herpotrichoides* Fron.

[8] SPRAGUE, R. CERCOSPORELLA FOOT ROT OF WINTER GRAINS IN THE PACIFIC NORTHWEST. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases. 1934. [Mimeographed.]

[9] EDSON, H. A., MILLER, P. R., and WOOD, J. I. DISEASES OF PLANTS IN THE UNITED STATES IN 1934. U. S. Dept. Agr., Bur. Plant Indus. Plant Disease Reptr. Sup. 90: 1–135. 1935. [Mimeographed.]

The disease in the United States is found in prairie sections of the Pacific Northwest. The climatic conditions that prevailed over this area from 1928 to 1935 (the several years that the study was conducted) are briefly discussed and correlated with the observed behavior of the disease.

The annual rainfall in the localities where foot rot is prevalent varies from 14 to 25 inches. The relation of the distribution of foot rot to rainfall is given in detail. It is also shown that variation in the time of seasonal rainfall influences the time when the disease develops. The rainfall in spring aids in spreading secondary infection in the fields.

In the semiarid area in which foot rot occurs soil moisture and precipitation are closely linked, especially toward harvest when the moisture that was originally in the summer-fallowed soil has been exhausted. Field and laboratory studies show that the greater the soil moisture (until near the saturation point) the greater the amount of foot rot. Foot rot thrives in those soils that have a low wilting point coefficient and that do not tend to become dry and baked. There are many complications that frequently obscure the effects of soil moisture on the development of the disease. Snowbanks, straw piles, soil types, rotation, and direction and pitch of slope all tend to modify the influence of soil moisture.

The relative humidity at the soil surface is also a vital point. The foot rot increases with an increase in relative humidity. The winds that are so frequent in the Columbia River Basin often save the grain from serious damage by drying out the surface soil. On the other hand, the wind may kill many culms by dehydration that have been weakened by disease through early spring attacks.

Good growing temperatures for the host are usually good growing temperatures for the parasite, but the fungus can thrive at lower temperatures than can the host.

Mean daily temperatures above 60° F. are considered nearly as effective as low soil moisture in checking the progress of the disease late in the season when high temperatures and low precipitation usually prevail.

Cercosporella foot rot occurs in portions of the Columbia River Basin where the mean temperature for the growing season (September to June) usually is between 40° and 45° F. (4° to 7° C.). *Cercosporella herpotrichoides* makes optimum growth at a soil temperature of about 10° C. (50° F.). It is able to grow readily at cooler temperatures but does not thrive at soil temperatures much above 15° C. (59° F.). The optimum temperature for growth in pure culture is 21° C. (69.8° F.), and the maximum 30° C. (86° F.).

Freezing temperatures injure the smaller, weaker culms of the host, permitting the fungus to infect them during early spring and thus increasing the amount of inoculum present in early spring, a situation likely to result in increased foot rot. However, freezing temperatures are not, in a direct way, as vitally important to the development of the disease as was formerly suspected.

Light does not influence the action of the fungus to any observable extent. Wheat plants that had been forced under artificial light fell prey to disease sooner than those not given supplementary light, but when the latter were permitted to reach the same stage as the former they showed essentially the same amount of infection.

Plants that have made the heaviest vegetative growth at an early date in the spring are most susceptible to the disease. To sustain a destructive attack of cercosporella foot rot heavy rains must occur in early and midspring season. The factors affecting the development of the disease are summarized in two-dimension graphs.

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